GROWTH AND COMPOSITION OF EUCALYPTUS AND MAIZE ON KENYA SOILS FERTILIZED WITH PHOSPHATE AND INDOLE ACETIC ACID

BY

Joseph Kipkorir A. Keter

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GROWTH AND COMPOSITION OF EUCALYPTUS AND MAIZE ON KENYA SOILS FERTILIZED WITH PHOSPHATE AND INDOLE ACETIC ACID

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Joseph Kipkorir A. Keter

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Three glasshouse experiments were conducted with three Kenya soils to determine plant responses to exogenous indole acetic acid (IAA) at 31, 62, and 124 g/ha and to concentrated superphosphate (CSP) in powder, pellet, or pellet (including IAA) forms applied at 28, 56, and 112 kg P/ha. Soils were taken from depths of 0 to 15 and 15 to 30 cm and two soils were Vertisols (Athi and Mwea) and the other a Latosol (Kabete). The soils were nearly similar in pH (6·3 to 6·8) but differed in soil test P by the double-acid method (DA-P) with values of 4·5, 7·0, and 550 ppm P for Athi, Kabete, and Mwea soils, respectively. Soil test for P by 0·5 M sodium bicarbonate (SB-P) was also used for Athi and Kabete soils.

Eucalyptus grandis was planted in the first experiment and early growth exhibited purplish leaves and stems on Athi and

Kabete soils, particularly without P added, attributed to P deficiency. At 2, 3, and 4 months, height of plants was greater where CSP was used compared to IAA and differed between soils. Tops weight, stem diameter, and tops P were significantly greater where CSP was present but only tops P increased with the amount of CSP forms applied. For each soil, highly significant linear regressions were obtained between tops P and either DA-P or SB-P, tops P and leaf P, and DA-P and SB-P. Fertilization with 28 kg P/ha resulted in tops P or leaf P above 0·110%.

On the above soils left undisturbed, Zea mays L. of cultivar 'Pioneer 3160' was planted. Plant height, tops weight, and tops P increased linearly with previous CSP rates and were lower for IAA. Highly significant linear regression relationships were found between tops P and DA-P for each soil and at each soil depth. Another study with maize after preplant fertilization of Athi and Kabete soils showed that root weight was higher where CSP was present and root P was less than leaf P or tops P.

INTRODUCTION

The greatest challenge facing most developing countries, especially those in tropical Africa, is the ability to (i) produce enough food for its people, and (ii) control the population growth. These countries have numerous other problems such as unstable governments, inadequate health care, too much dependence on foreign countries for most of the manufactured goods, high illiteracy, and failure to make full and wise use of the available natural resources.

Agricultural production in the tropics is principally controlled by rainfall, for in equatorial regions the temperature is fairly constant over the year. In most areas, the rainfall is never uniformly distributed throughout the year. Near the equator there are typically two rainy seasons a year.

The outstanding characteristic of the rainfall over most of tropical Africa from the agricultural point of view is that, averaged over the year, it is less than the amount of water a crop well-supplied with water would transpire. It is, therefore, necessary to restrict crop production to the rainy seasons or choose crops which will not suffer too severely if subjected to considerable periods of drought.

Agricultural production in the tropics can be intensified by developing methods for ensuring the best use of rain that falls on the land. These methods can be grouped into three categories: foremost are those which enusre that as much as possible of the

rain percolates into the soil, at least up to the amount the growing crop needs for a good yield. Secondly, those methods involving the choice of a crop and its management are needed so that its yield is as high as possible from the water that is actually available. Thirdly, there are those methods in which a crop is chosen and managed in order to minimize the harmful effects of drought during its growing season. These methods will not be considered in detail here but were only mentioned in order to specify further the agricultural problems of semi-arid areas of the tropics.

Semi-arid areas are not characterized by low rainfall every year, so that, in a certain proportion of years in these areas, crop yields are more influenced by the level of soil fertility than by the availability of water.

In most areas phosphate and nitrogen are the nutrients most likely to limit crop yields. In many areas of tropical Africa, the soils appear to be very low in phosphate, and crops usually respond well to phosphate fertilizers. It is now well-established that a phosphate fertilizer applied to a soil low in phosphate will increase yields for a number of years after application.

Effectiveness of P fertilizers is dependent upon chemical and physical characteristics of the fertilizer, rate of its use, and method of its application. Soil and climatic conditions under which the crop is grown, and crop characteristics also influence the effectiveness of P fertilizer.

Phosphorus fertilizers can be classified into three groups on the basis of their solubilities, namely: (i) those in which the P is mostly soluble in water, (ii) those not readily soluble in water but soluble in ammonium citrate, and (iii) those insoluble in ammonium citrate. Usually, the sum of (i) and (ii) represents the so-called available P.

It is found highly desirable to granulate fertilizers in order to facilitate handling and application and, possibly, also influence the agronomic value of the fertilizer in some cases. Granule size may influence fertilizer effectiveness in two ways. First, it affects the placement pattern or distribution of fertilizer in the soil; and second, it determines the effective surface area and the reactivity of the material.

Reaction of P with the soil to form largely insoluble products is less likely to be a limiting factor than rate of P dissolution in the case of slightly water-soluble P fertilizers. Consequently, small granules which provide a large surface area and ensure closer contact with and better distribution through the soil are generally assumed to be more effective than large granules. But in the case of highly water-soluble phosphates, rate of dissolution generally is of less concern than reversion or reaction with the soil to form less soluble compounds. The rate of P reaction with the soil tends to be less with large than with small granules.

Another factor that is important in considering water solubility and granule size relationships is method of application

of the fertilizer. Banding of the fertilizer tends to minimize contact and reaction with the soil. The zone of diffusion around a band becomes an enlarged version of the zone around a coarse granule. Such application tends to accentuate the value of a high degree of solubility. Broadcasting the fertilizer and mixing it with the soil maximizes fertilizer and soil reaction and favors the less soluble sources.

The study of growth control mechanisms is one of the most active fields of plant physiology. It is now evident that growth is controlled not by one but by several groups of hormonal substances as well as by numerous naturally occurring inhibitors which are still very incompletely understood. Information on indole acetic acid (IAA), one of the most widely studied substances, shows that it is produced mainly in meristematic and growing regions of shoots; senescent tissue has also been suggested. 1AA is found in most tissues. It moves readily from shoots to roots in phloem and more slowly by cell to cell by polar-transport, basipetally in shoots and acropetally in roots. 1AA promotes elongation of stems and coleoptiles, photo- and geotropic curvature, adventitious rooting and lateral root initiation, xylem differentiation, fruit growth, cambium activity and leaf epinasty. However, it can inhibit root elongation, leaf senescence and fruit abscission.

Production of 1AA is inhibited by Zn and P deficiencies and increased by gibberellins and cytokinins.

In maize crops, there is a close relationship between high-producing varieties, fertilizer, plant population and moisture condition of the soil. Another extremely important factor, particularly under African conditions is early planting, which means planting at the start of the rains. In Kenya, it has been found that planting after the rain has started causes significant reduction in yields. The actual size of the reduction in yield will vary according to such circumstances as the rainfall pattern and the soil characteristics. If the rainfall is not very heavy, and the soil has good structure and drains quickly, then the decline in yield from late planting will be smaller than if the rainfall is heavy, and the soil has poor structure and drainage. For that reason, intensive soil cultivation with the ploughing in of maize stover, is practiced where possible, in order to improve soil structure, and good soil drainage which are of the utmost importance.

Phosphorus promotes the development of the root system, aids in seed formation and hastens ripening of maize. The maize plant has a coarse, fibrous root system which spreads widely and penetrates deeply. Nevertheless the young plant has difficulty in taking up phosphorus from the less available phosphate forms in the soil. Maize is, therefore, often used as a test-plant to estimate the amount of easily available P in a soil. In order to stimulate early growth and development care should be taken to provide the crop with a sufficient amount of easily avaliable P.

The need to stimulate modern agriculture is urgent in Africa because the population is increasing at a faster rate than is food production. Most African countries import paper and yet they could produce trees such as eucalypt for their timber and paper needs. Cost of importing fertilizer and lack of capital restricts improvement of crop yields. There is need to use P fertilizers efficiently and effectively. If a method could be found to stimulate rooting of seedlings and early plant growth, this might also increase the efficiency of applied P by causing more root intercept of available P.

The present study was done with three Kenya soils in order to test if indole acetic acid could assist in improving the response of two test crops to P fertilization by stimulating root proliferation and plant growth. To check this hypothesis, pelletized CSP was made containing 100 ppm of indole acetic acid (IAA). The experiments consisted of three rates of CSP containing IAA compared to IAA without P. The effect of pelletized CSP without IAA was compared to CSP in powder form to be determine if pelletized CSP caused a different plant response. The first experiment was conducted with <u>Eucalyptus grandis</u> using three rates of IAA, and three rates of three CSP sources to check on the response to IAA and to pelletized P. The objective of the second experiment was to test for residual effects of CSP and IAA on <u>Zea mays</u> grown on these soils. The third objective was to determine if CSP and IAA or in combination applied preplant had an effect on maize responses.

LITERATURE REVIEW

Phosphorus

Occurrence of Phosphate Minerals

Phosphate minerals form under a wide variety of environmental conditions ranging from silicate melts, to natural soils, to ocean floors. In nearly all naturally occurring phosphates, P is pentavalent, even though tri-, quadri-, and hexavalent-P compounds are readily synthesized (Lindsay and Vlek, 1977).

X-ray diffraction has made it possible to determine the crystal structures of most orthophosphates. It was observed that the central P atom is surrounded by four O atoms forming an approximately tetrahedral structure (Lindsay and Vlek, 1977). This configuration is possible because of the formation of four σ-bonds after sp_3 hybridization and additional Π-bonding using d-orbitals. The structural formulas of these compounds are represented as having a double bond in order to satisfy classical valency requirements, but some sharing of the multiple-bond character occurs among the four O atoms.

The formation of stable atomic structures containing PO_4 tetrahedra is naturally accomplished through the high affinity of PO_4 for cations, particularly those exhibiting eightfold coordination.

Inorganic Phosphorus in Soils

Inorganic phosphorus in soils is believed to exist as sparingly soluble orthophosphates of Al, Fe and Ca. The Ca-P compounds such

as apatites are of primary origin. Al- and Fe-P, such as variscite ($AlPO_4 \cdot 2H_2O$) and strengite ($FePO_4 \cdot 2H_2O$) are generally believed to be the predominating ultimate end-products of inorganic P formed during soil genesis and P fertilization (Chakravarti and Talibudeen, 1962; Chang and Chu, 1961; Chang and Jackson, 1958; Hawkins and Kunze, 1965; Kittrick and Jackson, 1956; Lindsay _et al_., 1959; Taylor _et al_., 1963; Yuan _et al_., 1960). Soil test correlation studies have shown that, in acid soils, the Al-P fraction as determined by Chang and Jackson's procedure (1957) is more available to upland crops than the Fe-P fraction. There is evidence that the Ca-P fraction is the least available of the three fractions (Chang and Juo, 1963; Hanley, 1962; Payne and Hanna, 1965; Susuki _et al_., 1963; Smith, 1965).

In soil, most of the inorganic P occurs in the clay fraction from which it cannot be separated by physical methods (Larsen, 1967). Consequently, direct evidence of the nature of the inorganic P cannot be obtained by known petrographic methods. Only when P has been separated from the soil (or formed in layers or pockets in the soil by natural processes) can a sufficient concentration of P minerals be obtained for direct petrographic examination. So far, only the P minerals apatite, vivianite ($Fe_3(PO_4)_2 \cdot 8H_2O$) and wavellite ($Al_3(OH)_3(PO_4)_2 \cdot 5H_2O$) have been qualitatively determined in soil by such methods (Black, 1957).

A semiquantitative method for the direct determination of soil apatite was developed by Shipp and Matelski (1960). Although this method provides a direct way of detecting apatite minerals,

it does not distinguish between the various forms of apatite, such as fluoroapatite and hydroxyapatite.

Chang and Jackson (1957) attempted to classify inorganic soil P into different fractions, according to their extractability in various reagents. Since the reagents are very likely to cause a redistribution of the phosphorus during the extraction, such methods must be arbitrary. In view of this, the compounds reported to be in the soil may not have been actually present in the original soil.

Reactions of Phosphorus in Soil

Lehr and Brown (1958) and Lehr et al. (1959) identified $CaHPO_4 \cdot 2H_2O$ (dicalcium phosphate dihydrate), $CaHPO_4$ (dicalcium phosphate anhydrous), $Ca_4H(PO_4)_3 \cdot 3H_2O$ (octocalcium phosphate), and apatite in soils following the application of superphosphate. The particular compounds formed depended upon soil properties. Moreno et al. (1960a, 1960b) determined the solubility and stability of dicalcium phosphate dihydrate and octocalcium phosphate.

Cole and Jackson (1950, 1951) made preparations of $AlPO_4 \cdot 2H_2O$ (variscite), $FePO_4 \cdot 2H_2O$ (strengite) and other compounds and hypothesized their probable formation in soils was as phosphate fixation products. Haseman et al. (1950, 1951) showed that under certain conditions complex crystalline phosphates of iron and aluminum were formed when clays or iron and aluminum oxides reacted with phosphate solutions. Kittrick and Jackson (1955) reacted soil minerals with phosphate solutions and, by use of the electron microscope, presented evidence of the formation of new P, crystalline phases.

Lindsay and Stephenson (1959) repeatedly reacted a series of soil samples, first with a solution saturated with respect to $Ca(H_2PO_4)_2 \cdot H_2O$ (monocalcium phosphate monohydrate) and $CaHPO_4 2H_2O$ (MTPS, that is, metastable triple-point solution), and later with water, in an attempt to simulate the changing chemical environment of soil surrounding a superphosphate granule. They found that the reaction of MTPS with soil was accompanied by an increase in pH and precipitation of Fe, Al, and Ca phosphates from solution. Soil repeatedly contacted by MTPS gradually became more acidic and showed continued dissolution of Fe and Al. Subsequent additions of water to the soil residues remaining after reaction with MTPS increased the pH and caused further precipitation of phosphate from solution. Many filtrates obtained during these reactions yielded precipitates upon standing. They identified the following crystalline compounds from these precipitates:

$CaHPO_4 \cdot 2H_2O$, $H_6K_3Al_5(PO_4)_8 \cdot 18H_2O$
$H_8K(Al,Fe)_3(PO_4)_6 \cdot 6H_2O$, and $CaHPO_4$

Lindsay and Stephenson (1959) also suggested that the indications are that these compounds may form as initial phosphate reaction products of superphosphate fertilizers in soil.

Bell and Black (1970) compared the methods for identifying crystalline phosphates produced by interaction of orthophosphate fertilizers with soil. In soils that were treated with $Ca(H_2PO_4)_2 \cdot H_2O$, $NH_4H_2PO_4$, and $(NH_4)_2HPO_4$, various methods were investigated. These ranked as follows in decreasing order of sensitivity: optical examination of soil $\geq$ optical examination of

glass-fiber filter paper inclusion > X-ray diffraction examination of glass-fiber filter paper inclusion > X-ray diffraction examination of soil.

Adsorption Reactions

The reaction of fertilizer P with soil depends upon the nature and amount of adsorbing surface as well as pH and other factors. Olsen and Watanabe (1957) found that adsorption of P by soils from dilute solutions showed a closer agreement with the Langmuir isotherm than with the Freundlich curve. The adsorption maximum calculated from the Langmuir isotherm was closely correlated with the surface area of soils as measured by ethylene glycol retention.

Regression analysis of phosphorus adsorption as a function of five soil characteristics indicated that organic matter is important in the initial bonding of P by soils (Harter, 1969). He proposed that P is initially bonded to anion exchange sites on organic matter, and subsequently transformed into less soluble iron and aluminum phosphates.

Rajan and Fox (1975) studied phosphate adsorption by several Hawaiian and Indian soils, and the relation of phosphate adsorption to hydroxyl, sulfate, and silicate ions released in two Hawaiian soils. Adsorption isotherms of some of the soil showed an abrupt increase in phosphate adsorption at high concentration.

They analyzed the isotherms by applying a binary Langmuir equation (assuming two types of sites). They observed that phosphate adsorption is associated with increased pH and sulfate

release at low levels of phosphate adsorbed and increased silicate release throughout. According to Rajan and Fox (1975), these observations suggest that, at low concentrations, phosphate exchanges with (i) adsorbed sulfate and adsorbed silicate, and (ii) with water and hydroxyls of metal hydrous oxides and edge Al of clays. At high concentrations, additional phosphate is adsorbed by displacing the structural silicate of clays. The increase in phosphate adsorption by structural silicate release, over that of surface exchange reactions, was about 50 and 25% in two soils containing kaolinite and allophane, respectively.

Mekaru and Uehara (1972), using the difference in pH of a soil suspension prepared with 1N KCl with water to determine net charge of colloids with constant potential type surface, found that the quantity ($pH_{KCl}-pH_{H_2O}$), called delta pH, had a positive, zero, or negative value corresponding to the net surface charge. Negative and positive adsorption of chloride or nitrate ions were measured in soil suspensions with negative and positive delta pH, respectively. They found that increasing the nitrate ion concentration increased sulfate adsorption in suspensions with negative delta pH values. Negative adsorption of nitrate and chloride ions was measured when sulfate ions were added to a soil colloidal suspension which had initially a net positive charge. Their belief that specifically adsorbed anions render a surface more negative by displacing the zero point of charge to lower pH values was supported in their observations.

Furthermore, this was substantiated by a measured increase in cation exchange capacity (CEC) over an initial value of 26 meq/100g in a phosphated soil. Each millimole of adsorbed phosphate increased the soil CEC by 0.8 meq.

Langmuir plots of P adsorption isotherms of four soils were shown to fit into two intersecting lines (Taylor and Ellis, 1978). These workers investigated the mechanism of P adsorption on soil and anion exchange resin surfaces at low equilibrium concentrations. The adsorption data were also found to fit the BET (Brunauer, Emmett, and Teller) equation. The monolayer capacities computed from the BET equation were found to correspond closely with the adsorption maxima computed from the initial slopes of the Langmuir plots.

Taylor and Ellis (1978) concluded that, at low concentrations, P was bonded by two points of attachment after deprotonation of the $H_2PO_4^-$ ion, followed by one point of attachment at higher P concentrations during adsorption on the resin surface. This resulted in the deviation from linearity predicted by the Langmuir equation.

Movement of Phosphate Ions in Soil

The mobility of P applied as diammonium orthophosphate (DAP), triammonium pyrophosphate (TPP), or ammonium polyphosphate (APP) was studied by Khasawneh et al. (1974) in columns of a fine sandy loam. They observed dissolution of the fertilizer in soil moisture that moved towards the P-application site. This water movement was sometimes against a gradient in soil moisture content, but it was along a gradient in the total potential of soil water.

They found that the extent of P movement from all three sources was similar, but that the distribution patterns were different. The extent of P movement was influenced more by the initial soil moisture content than by the source of P. They also noted that a higher fraction of the added P was precipitated when the source was TPP or APP than when it was DAP. The ability of the polyphosphates to sequester soil Fe and Al did not prevent the precipitation of these phosphates nor did it make them more mobile than the orthophosphates. They found APP only delayed the precipitation reaction to a degree that depended on the polyphosphate content of the fertilizer material.

Hydrolysis and sorption of pyro- and poly-phosphates in soil have been studied by many workers. Sutton and Larsen (1964) and Sutton et al. (1966) measured rates of hydrolysis of pyrophosphates in soil, and found that hydrolysis was largely enzyme-mediated and related to the overall biological activity as measured by CO_2 evolution. Gilliam and Sample (1968) found that either sterilizing soil by fumigation with CH_3Br or by autoclaving did not completely stop hydrolysis, indicating that chemical as well as microbial factors in the soil determine the rate of pyrophosphate hydrolysis. Hashimoto et al. (1969) reported that hydrolysis ceased when concentration of pyrophosphates in a soil suspension exceeded 0.2M. They also reported that pyrophosphate was adsorbed more strongly than orthophosphate on soils and clay minerals. Sutton and Larsen (1964) had reported just the opposite for soils in England. Their data indicated that

ortho-phosphate was adsorbed more strongly than pyrophosphate by soil, but that these soils had higher adsorption capacity maxima for pyrophosphate than for orthophosphate.

Khasawneh et al. (1974, 1979) discussed the comparative mobility of ortho- and polyphosphates in soil and related it to two soil processes:(i) reactions of these phosphates with soil, and (ii) biologically catalyzed hydrolysis of the poly-phosphates. In their view, diffusive movement of phosphates away from granule or band sites is basically by salt diffusion where equivalent amounts of cations and phosphatic anions are involved. They reasoned that since fertilizer solution is initially very concentrated in both phosphates and NH_4^+, subsequently NH_4^+ readily replaces exchangeable cations, such as Ca, Mg, K, and Al. These cations, however, when combined with orthophosphates form salts that are rather insoluble and may be rapidly precipitated in situ in soil, or their precipitation may be delayed to the extent that if the solution phase is separated from the soil, precipitation occurs thereafter (Lindsay et al., 1962).

Lindsay et al. (1962) reported that considerable amounts of soil Fe and Al were dissolved by solutions of ammonium ortho- and polyphosphates, indicating that reaction of concentrated solutions of ammonium phosphates is not limited to exchangeable cations. For example, ammonium polyphosphate solutions dissolved 63 μmoles of Fe/liter and 8 μmoles of Al/liter when added to $Fe_2O_3 \cdot H_2O$ and $Al(OH)_3$, respectively. Hashimoto et al. (1969) reported that 25 ml of a 2.0M solution of triammonium pyro-phosphate dissolved

65 mg of Al from gibbsite and 10 mg of Fe from goethite in a 2-day period. They found that similar solutions were much less reactive with kaolinite and montmorillonite.

In a study on the effects of cations associated with reactions of ammonium ortho- and poly-phosphate fertilizers in soil, Sample et al. (1979) found that, in general, the NH_4^+ ions derived from the fertilizer salts moved in association with the phosphate anions in the form of salt diffusion, and also moved by counter diffusion in exchange for some of the exchangeable soil cations. Exchangeable Ca in the first 6 mm of soil contacted by the fertilizer solution from diammonium phosphate (DAP) was replaced by NH_4^+, and the displaced Ca^{2+} was precipitated in place by phosphate. Displaced Ca was transported in the fertilizer solution of triammonium pyro-phosphate monohydrate (TPP) and ammonium polyphosphate (APP) for 6 to 8 mm before it was precipitated. Reactions of phosphates with displaced Ca^{2+} caused its activity in these soil zones to drop sharply and created a Ca gradient opposite to that of the phosphates. They observed that depletion of exchangeable cations, especially at or just beyond the fertilizer solution front, caused soil pH to drop as much as one pH unit below the initial soil value. Within the soil zone affected by phosphates, pH was about 7.5 with DAP and 6.7 to 7.2 with APP and TPP. Differences in pH between soil in the outer zones reached by phosphates and the inner layers ranged from 1.7 to 2.7 pH units.

In the study by Sample et al. (1979), it was found that soil Al was influenced greatly by all three fertilizer solutions so that with DAP, the reaction products simply reprecipitated in place without undergoing any movement. The observed increased acid extractability was the only evidence of the presence of fresh precipitates involving Al. They determined that in addition to such a reaction, movement of Al occurred with TPP and APP, and there was evidence of rather-well-defined zones of precipitation involving Al pyro- or polyphosphates. They did not find evidence to implicate Fe in reactions similar to those for Al.

Mechanisms Affecting Ion Distribution

Barber (1974b) discussed factors which affect ion movement in soil. Root interception, mass-flow, and diffusion were considered as affecting ion distribution. They measured nutrients as concentration per unit volume of soil when diffusive flow to plant roots was determined. Hence they observed when the bulk density of soil is increased near the root, that the concentration of available nutrients per unit soil volume is also increased. This increase results in a greater concentration gradient for nutrients diffusing to the root (Barber, 1974b). They suggested that roots may also encounter some nutrients and absorb them as it forces its way through the soil.

Oliver and Barber (1966) calculated the ions displaced by the roots as a supply mechanism, although some ions may be pushed away and return to the root by mass-flow and diffusion, they assumed that the amount of ions returning to the root would be in

additon to the amount for mass-flow and diffusion. They found that the root did not influence soil bulk density near the root surface.

Barber (1974b) stated that, since plant roots absorb water, they caused a flow of water from the soil to the root surface and this water contains inorganic ions as well as soluble organic molecules. He reported that such ions are mass-transported to the root in the convective flow of the water and that the amount of ions reaching the root depends upon the rate of water flow to the root and the average ion content of this water. He also stated that when the concentration of a given ion at the root surface is reduced, a concentration gradient normal to the root is established because the ion diffuses toward the root due to the thermal motion of the particles. His research indicates that the ion supply to the root and the rate of uptake is largely regulated by the rate of diffusion. He considered that diffusion follows Fick's law, which is

$$F = - DA(\partial c/\partial x),$$

where F is the amount diffusing per unit of time, t; D is the diffusion coefficient; A is the area for diffusion; and $\partial c/\partial x$ is the concentration gradient. Since diffusion to a root is in radial coordinates, the appropriate equation becomes more complex. A simplified version of this equation was given by Passioura (1963) as

$$F = - A[(C-Co)Dk/r_o]$$

where C is the initial total concentration of the nutrient in the soil; Co is the concentration at the root surface; r_o is the root

radius; k is a monotonically decreasing function of Dt/r_o^2; and t is the time that the sink has been operating. He considered that the soil reacts chemically with many of the nutrients that diffuse to the root and also physically makes the diffusion pathway more tortuous.

The value of D in a soil reflects the reduction in rate of diffusion because of the chemical reaction and the increase in tortuosity because of physical factors (Barber, 1974).

Nye (1968) proposed a simple method for calculating the value of D for phosphate ions as follows;

$$D = D_1 f_1 V_1 (dC_1/dC)$$

where D_1 is the diffusion coefficient of P in free solution ($8{\cdot}9 \times 10^{-6}$ cm^2/sec); f_1 the impedence or tortuosity factor; V_1 the volumetric water content; and $dC_1/dC = {}^1/b$ which is the reciprocal of the slope of the P adsorption isotherm.

Rate of P diffusion from fertilizer applied at the soil surface was studied by Hira and Singh (1978) using Fick's Law of diffusion. They determined the diffusion coefficient of P from a knowledge of the tortuosity factor and P adsorption isotherm. Phosphorus diffusion coefficient calculated from Nye's equation did not prove suitable at very low or high concentrations of P at the soil surface. The P diffusion coefficient calculated from their experimental data increased linearly with the square root of P concentration applied at the source. They stated that the P diffusion coefficient could be

calculated from the equation,

$$D = \frac{D_1V_1f_1}{b}(Q)^{\frac{1}{2}}$$

where Q is the material applied uniformly on a surface (mg/cm^2). Their predicted P concentration-distance profiles were found to be very close to the experimental values estimated by employing a sectioning technique.

Chien et al. (1980) derived a modified Elovich equation in the form of

$$C_t = Co - (^1/\beta)\ln(\alpha\beta) - (^1/\beta)\ln C_t$$

where α and β are constants, t is time, and the term C_t and Co are given below. They described the kinetics of dissolution of three phosphate rocks (North Carolina, central Florida, and Tennessee) in three soils (one soil from Florida and two Nigerian soils). They compared the values of Co, α, and β in the equation with the dissolution rates of various phosphate rocks in a given soil or a given phosphate rock in various soils. In this case, Co is the maximum P concentration in the soil solution that a phosphate rock can provide in a soil (C_t is the P concentration at time t).

Chien et al. (1980) found that Co increased as α increased and/or β decreased in a given system. They failed to find any significant effect of temperature on the dissolution of phosphate rock in the soil. This implied that P retention by the tropical soils treated with phosphate rock may be much less affected by temperature than when compared with water-soluble P fertilizers such as concentrated superphosphate.

In a study of phosphate sorption by acid, sandy soil, Fiskell et al. (1979) measured phosphate sorption by two soils with time using a laboratory batch technique for a range of initial P concentrations in solution. They compared experimental data with results calculated using a two-site sorption-desorption model and found that, for contact times > an hour, they observed that P sorption in both the sandy soils could be described by assuming rapid and slow reversible reactions to occur simultaneously at two separate types of sorption sites. But for contact times < 60 minutes they found that the 2-site model did not describe the P sorption adequately. At the rapid and slow sorption sites, the orders of the forward reactions were fractional and first-order, respectively, with regard to the P concentration in solution. For a given soil, one set of rate coefficient values was sufficient to describe the solution phase concentration of P for several different initial concentrations.

Chien and Clayton (1980) derived a simple modified Elovich equation in the form:

$$q = ({}^{1}/\beta)\ln(\alpha\beta)+({}^{1}/\beta)\ln t$$

where q is the amount of phosphate released or sorbed and α and β are constants and t is time. They attempted to fit various experimental data reported in literature that failed to conform to a single first order kinetic equation. Using this equation, they successfully described the data as a single straight line that covers the entire span of reaction time. They suggested that it appeared that constants α and β may be used for comparison of reaction rates of phosphate release or sorption in different soils.

Effectiveness of Phosphate Fertilizers

Terman (1957) reported that for 433 P rate and source experiments in 7 Southeastern states of the Unites States of America, the distributions of the coefficients of variation (CV) (or standard errors per plot in percent) for corn, cotton, legume, legume-grass hay and small grain were similar. It was found that C.V. values were negatively correlated with yield levels for all crops and standard errors per plot were positively correlated with yield for corn and alfalfa but not significantly for cotton and wheat. They noted that there were no consistent interactions between P sources and rates.

Webb et al. (1959) reported on field research dealing with the importance of water solubility of P in fertilizers applied broadcast and plowed under for corn. Highly water-insoluble sources tended to be slightly less effective in a few of these experiments. But their general conclusion was that, on the soils included in the study, the degree of water solubility of the P was not a significant factor in determining the effectiveness of fertilizers applied by this method. All of the experiments in that study happened to be located on acidic or nearly neutral soils, which raised the question of whether similar results would have been obtained on calcareous soils.

In later experiments, Webb et al. (1961) conducted five field experiments in which several slightly water-soluble P sources were compared with concentrated superphosphate (CSP) for use in broadcast applications for maize (Zea Mays L.).

These tests were located on calcareous soils which tested low in available P. Based on their effect upon the concentration of P in corn leaves and upon corn yields, CSP and dicalcium phosphate dihydrate were found to be the most effective sources, with the former being slightly superior. Anhydrous dicalcium phosphate, calcium metaphosphate, and a chemical blend of mono- and dicalcium phosphate were of intermediate effectiveness, producing yield increases of about 70 to 80% of that given by CSP. Granular calcium metaphosphate was the least effective source, being about 60% as effective as CSP in promoting yield increases. They concluded that, on calcareous soils, a highly water-soluble source of P, such as CSP, is likely to be more effective in broadcast applications for corn than are most slightly soluble P sources. They noted, however, that other characteristics of the fertilizer may be of equal importance in determining their effectiveness.

In growth chamber and field studies with maize, McLean et al. (1965) employed partially acidulated rock phosphate (with H_3PO_4) to study its effect on the yields and P content of German millet and alfalfa (Medicago sativa L). Growth in the chamber increased to a maximum at 72 kg P/ha and 20% acidulation on one group of soils and continued to increase with application rate and acidulation degree in another group. They did not obtain any appreciable difference with three methods of preparation of 20% acidulated material. Average field corn yield on the five above soils was highest with 20% acidulated material, resulting in marked economic advantage of this material.

McLean and Logan (1970) evaluated several phosphates which differed in water solubility as sources of P for plants grown in soils with varying degrees of P retention. They reported that, with relatively low P retention, P content of maize seedlings increased in direct proportion to the P water solubility, but soils with high P retention resulted in content that decreased with increased water solubility of P.

In experiments with maize, Meelu et al. (1977) found that all P sources at 60 kg P_2O_5/ha were equally effective with evidence of luxury uptake of P from water-soluble P sources. All P fertilizers had a residual effect and soil test for P was significantly correlated with yield of successive crops.

Infertile soils were used by Mortvedt and Terman (1978) to grow maize in three greenhouse pot experiments where the soils had received 0-800 mg P/pot as CSP, MAP, a 30:70% mixture of CSP and MAP or a 10:90% mixture of CSP and MAP. Responses were greatest for MAP at adequate P levels and occurred at rates much higher than normally recommended for field experiments.

Pelletized Phosphate

The main objective of coating granules of water-soluble phosphates is to reduce fixation of applied P by the soil, thereby increasing its availability for crop growth. Negative results have usually been obtained, however. Terman et al. (1970) reported no response of a first crop of flooded rice to P in S-coated CSP, but the P became available to a second crop after degradation of the coating. Allen and Mays (1971) found that

insufficient P was released from S-coated DAP for early growth of forage sorghum (Sorghum bicolor L.) and resulted in lower total yields than did uncoated DAP.

Nicholaides et al. (1979) compared pelletized ordinary superphosphate (OSP), uncoated CSP, or coated with S and sealant (SCSP) in a Rhodic Paleudult (a Red Bay, fine, sandy loam), previously uncultivated. They obtained the increase in corn grain yield for the first 28 kg P/ha and further response was linear at 200 kg/ha yield for each additional 28 kg/P applied. They found that field response was not significantly different either for P sources or for P placement. They observed no grain yield advantage to blending OSP and SCSP pellets either in the first or third year. Their soil test values and ear leaf P values showed linear responses to rates of applied P.

Phosphate Placement

Fertilizer is considered to be broadcast when applied over the entire soil surface. While most fertilizers are applied in this way (with subsequent incorporation) broadcasting may also include topdressing on growing crops. Broadcast P, however, is generally applied prior to planting since the growing plant needs P early in its development.

Acidulated P materials to be broadcast on acid to neutral soils generally do not need to be high in water-soluble P as discussed above. Field data showed that water solubility of broadcast P fertilizer on acid to neutral soils was not important (Webb and Pesek, 1959). However, water solubility of P fertilizer broadcast on calcareous soils was found to be quite important (Webb et al. 1961).

Application of P is needed less frequently if higher rates of P are used. In a rotation experiment, Barber (1969) broadcast P fertilizer once every 4 years at rates of 98 and 196 kg P/ha over a 16-year period. Both rates were effective in maintaining yields through the fourth year following each application. He concluded that more flexibility in P application is possible without seriously affecting yield, provided that the P is plowed under or mixed deeply into the soil.

Field experiments were conducted at three locations in Nebraska and one in Illinois by Cihacek et al. (1974) to compare alternative P application techniques for corn. These were chisel-broadcast, chisel placed (at 18- to 20-cm depth), chisel-row band, and moldboard-broadcast. Results of 3 years of experiments showed that the moldboard incorporation of broadcast P was the most effective combination. It was concluded, however, that tillage effects were more important than placement of P.

In field trials on an Oxisol in Brazil, P rate and placement were examined for maize grain yield (Yost, 1978). Their maximum yields were obtained where 560 kg P/ha were initially broadcast and where 140 kg P/ha were broadcast initially followed by consecutive band application of 35 kg P/ha for each crop.

It is usually recommended that for row and band P applications, the P source should be largely in water-soluble form in order to stimulate growth. Webb and Pesek (1958) studied the effect of a range of water-soluble P content from 2 to 100% of the available

P placed at 2.5 cm to the side and 4 cm below maize seed planted in 100- by 100-cm hills. Their increase in yield with higher water-soluble P content was quite marked.

In soils of Tanzania, 40 or 80 kg P/ha were applied by (a) broadcasting on the soil surface after sowing maize, (b) side dressing after sowing, and (c) drilling 2 to 3 cm below seeds in the planting furrow. When they compared unfertilized control grain yield of 2.5 t/ha to those with P placement methods (a), (b), and (c) grain yields increased by 200, 700, and 900 kg/ha, respectively, at 40 kg P/ha. At the higher P rate, method (a) gave yields alike those found for 40 kg P/ha applied by method (b) or (c). They studied interactions between applied N and P using 0, 40, 80, or 120 kg N/ha and 0, 30, 60, 90, or 120 kg P/ha. These maize yields increased linearly with N rate and this effect was enhanced where 60 kg P/ha was applied. Leaf P content increased linearly with increased rates of P supplied alone or with N. (Uriyo et al., 1980).

Bates (1971) summarized the response from selected treatments of 22 field trials in which normal tillage (plowing and disking) was practiced, and in which P and K were plowed down or banded beside and below the seed either as row or starter placement. He reported that, in only 2 out of 22 field experiments in Ontario, did maize yield increases result from starter fertilizer.

In Australia, Rudd and Barrow (1973) found that when superphosphate was row-placed for wheat, it was about twice as effective as that applied broadcast at seeding. Prummel (1956)

found similar results for several crops including maize, and small grains on P-deficient soil in the Netherlands. Welch et al. (1966) investigated the relative efficiency of broadcast versus banded P and reported that banded P for row crops can be more effective than broadcast P at lower rates of application. However, highest yields were obtained with a combination of banded and broadcast P. This agreed with the findings of Barber (1958) for corn that banding alone on low P soils is inadequate and the supplementary broadcast P is needed to reach top yields.

Barber (1974b) introduced the concept of strip application of fertilizer P as a compromise between broadcast and row placement. He found that surface placement of fertilizer in narrow strips before plowing was more effective than either banding or broadcast-plowing treatments alone. This strip application resulted in 8 to 10% of the plow layer being affected by fertilizer P after plowing.

Little data are available to indicate the effectiveness of surface-applied fertilizer in continuous no-tillage systems of corn production. In one of the few studies with P fertilizers applied to the soil surface for corn production and not incorporated, Singh et al. (1966) found higher P uptake from surface-applied P than P incorporated into the soil.

Surface application of P and K fertilizer to meadow crops has been more effective than incorporation of the fertilizer in the plow layer prior to establishment (Stanford et al., 1955). Broadcast applications of P and K fertilizer have also been effective on established meadow crops (Adams et al., 1967; Templeton et al., 1966).

Belcher and Ragland (1972) concluded that if P was surface-applied in a no-till system, it was equal in effectiveness to P incorporated into the soil. Several workers have shown no-till corn yields to be equal to or higher than those obtained by conventional tillage (Meschler and Martens, 1975; Triplett and Van Doren, 1969). They stated that the P source used for surface application should be largely water-soluble.

Fluid Fertilizers

The term fluid fertilizers is usually used to include both fertilizer solutions and suspensions (Engelstad and Terman, 1980). These workers proposed that, for a valid comparison of fluid and solid fertilizer P, the P should be supplied in the same chemical compounds in both cases and be similarly placed so that they have comparable contact with soil and proximity to developing root systems.

Lathwell *et al*. (1960) summarized the results of a number of field experiments conducted to compare P sources in solution and solid form, involving maize, other field crops, and cotton (*Gossypium hirsutum* L.). They concluded that P in solution form is as satisfactory as in comparable solid sources, but is likely to be superior to those solid materials which contain a large proportion of water-insoluble P. They suggested that the price per unit of P applied in the field should be the main criterion in choosing between solid and solution forms of P.

With suspension fertilizers, the P applied is usually quite insoluble. Finely ground phosphate rock for direct application

can be applied in suspension form rather conveniently and avoids dust problems as well. In this way, the material can be applied in finely divided state as it should be for greatest effectiveness (Engelstad and Terman, 1980).

Residual Phosphorus in Soils

The use of optimal amounts of P for intensive cropping enables most soils to accumulate residual P (Johnson et al. 1969; Olsen et al. 1978). In drier areas where extensive cereal cropping is practiced, the soils often remain deficient when annual fertilizer use has been minimal. In Saskatchewan, soil-available P was enhanced by the continued use of 20 kg P/ha or more with wheat in a 3-year rotation (Spratt and McCurdy, 1966). Both Read et al. (1977) and Bailey et al. (1977) found that large amounts of P (100 to 400 kg P/ha) incorporated in the soil could support cropping on Chernozem soils for several years.

Red soils of the warm and hot humid regions generally have inherently low levels of available P and high P-fixation capacities. De Datta et al. (1963) found that three latosol soils immobilized over 98% of the added fertilizer P. Woodruff and Kamprath (1965) found that the Georgeville soil (high in hydrated Al and Fe oxides) had a P-adsorption maximum of 720 kg P/ha, P as calculated from the Langmuir adsorption isotherm. They obtained optimum growth in a greenhouse study with 25% saturation of the P-adsorption maximum.

Band applications of normal rates of phosphate fertilizers have been suggested on red soils for maximum effectiveness of

the P. However, Barber (1965) pointed out that band applications of phosphate supply P to plants primarily during the first few weeks of growth. He maintained that for maximum economic yields soils should be high in nutrients throughout the root zone rather than in one spot.

In a study of the residual effect of large applications of P on high P fixing (red) soils high in hydrated iron and aluminum oxides, Kamprath (1967) found a marked residual effect of P applied 7 to 9 years beforehand. They found that, even when P was added in the row, corn yields were as much as 50% higher when high rates had been applied 9 years before. This indicated that the P added initially was not irreversibly lost, but was available for plant growth in later years.

The residual value of P in soils depends upon the nature of the compounds formed when phosphate fertilizers react with soil components. Several investigators (Ghani and Islam, 1946; Kaila, 1965; Lavery and McLean, 1961; Robertson et al., 1966; Singh et al., 1966; Volk and McLean, 1963) have reported large recoveries of P in the Al and Fe form where phosphated soils were subjected to fractionation into the various extractable compounds.

According to Chang and Jackson (1958), calcium and aluminum phosphates are likely to be formed soon after the application of phosphate fertilizers to mineral soils, and as time lapses, iron phosphate would be expected to form. In acid soils, the calcium ion activity may be of such low magnitude that calcium phosphate may not exist at all.

Bowman _et al_. (1978) evaluated four P extraction methods--Olsen-P, Colwell-P, total exchangeable P, and resin-extractable P--in terms of total plant P uptake in a 3-year continuous greenhouse study of 23 calcareous and neutral soils high in P status. All methods were highly correlated with the total P taken up from the soils by 5 to 8 successive greenhouse crops. They found that the Olsen-P method extracted an average of nearly 50% that of the total plant P, while the Colwell procedure extracted nearly 80% of it. Resin-extractable P and total exchangeable P values approximated the total plant P uptake, and served as good biological measures of the total plant-available P in the soil.

Maize

Utilization of Phosphorus

The levels of P availability in soils required for optimum crop production vary among the different crops. Maize is significantly more responsive than soybeans (Glycine max L.) to fertilizer P application, as reported by de Mooy et al. (1973). Another study reported for maize-soybean cropping system, found it was advantageous to apply the P fertilizer for the maize crop (Hanway and Olson, 1980). Similarly, wheat (Triticum aestivum L.) responds to P at higher soil P levels than required for maximum yields for maize, presumably this is related to the fact that wheat makes most of its growth under colder soil conditions than maize (Olsen et al., 1962). Some examples of the effects of certain P sources on the growth of maize have been given above.

Terman et al. (1975) found that differences in nutrient absorption between maize hybrids was apparently influenced by genetic effects on growth rates and yield potentials. Herbage yields increased with increasing levels of applied Zn only where 167 ppm P was also supplied. Content of P in the tissue increased in response to the increase in rates of applied P.

Maize grown in glasshouse experiments in soils from 68 locations in southeastern Nigeria responded in dry matter yields to P applied up to 56 kg P/ha (Enwezor, 1977). When available P levels were less than 34 kg P/ha, maize yields responded to applied P at 28 and 56 kg P/ha.

A study by Creamer and Fox (1980) on the toxicity of banded urea or diammonium phosphate to maize showed both banded urea and diammonium phosphate were toxic to maize root growth. They attributed this to ammonia toxicity which was favored when the initial soil pH was increased and the soil moisture content accumulation had little effect on the root-toxicity symptoms.

Research in Kenya

In Kenya, a series of trials at Kitale showed that sowing date and cultivars were the most important factors affecting maize yields (Allan, 1974). Plant density and weed control were also factors determining yields. It was found that early sowing increased yield of both poorly managed and optimally grown maize.

In another study of the association between altitude, environmental variables, maize growth and yields in Kenya, Cooper (1979) found that the potential number of maize grains per embryonic primary ear was greatest at low altitude but the final number of grains per ear at harvest was greatest at high altitude. Growth stopped abruptly at 69, 83, and 96 days after tasselling at low, medium, and high altitudes, respectively. Yields decreased with decreasing altitude and this was closely related to the mean thermal growth rate during the grain initiation period.

Indole Acetic Acid in Maize

Auxin action of indole acetic acid (lAA) in maize has been investigated by many workers. Edwards and Scott (1977) studied

the effect of 1AA on maize root segments in a citrate-phosphate buffer at pH 4 and pH 7. At neutrality, 0.1μ_M_ of 1AA promoted cell elongation only briefly whereas at pH 4 the rate was five times greater. They noted that elongation rate for root segments was much less than that for elongation rate of coleoptile segments when exposed to 1AA at pH 6.8. Investigations by Davies _et_ _al_. (1976) with resin beads containing 1AA placed at 0.5, 2, or 5 mm from maize root tips showed that only 10% of the 1AA was in the growing zone compared to that at the extreme root tip after 4 hours. They proposed that endogenous 1AA could move to the growing zone of the root tip and might unilaterally inhibit growth if it was in the transport pool as exogenous 1AA. Other studies by Naqvi (1976) used ^{14}C-2-1AA at 0.05 to 1.6 mg/liter on maize coleoptile segments and found that the highest efficiency for absorption and translocation of 1AA was when the applied 1AA was from 0.2 to 0.4 mg/liter. Research by Pernet and Pilet (1976) with 1AA applied to maize root caps showed that the 1AA entered the root tip and moved basipetally inside the cap and they concluded that the polarity of 1AA resulted in very slow transport from the cap to the apex.

The biosynthesis of 1AA in aseptically cultured maize roots in media containing ^{14}C-tryptophan or ^{14}C-1AA was demonstrated by Feldman (1980). He reported that exogenously supplied 1AA was rapidly and completely metabolized by root tissues and that the root apex was the main site for synthesis of 1AA. This was

shown by 1AA continuing to be synthesized at the apex after the root cap and quiescent center were removed from the apex. The level of 1AA of roots grown in this medium appeared to be precisely controlled by the roots. In maize cultivars resistant to low temperatures, Zaric (1978) found that the 1AA content of the coleoptile was higher at 25°C than at 1°C but this effect was reversed with cultivars susceptible to low temperatures. They found that at the 3-leaf stage, 1AA content was the same for the two sets of cultivars. Myo-inositol esters of 1AA were applied to cuts in maize endosperm and were shown to be transported at 400 times the rate of transport of 1AA in studies by Nowacki and Bandurski (1980). They suggested that free 1AA may be limiting for plant growth since esterification of 1AA occurred in the shoot and not in the endosperm.

Other workers have found that accumulation of 1AA by maize coleoptile sections was pH-dependent (Edwards and Goldsmith, 1980). They noted that a short-term uptake of 1AA in the sections was increased as the buffer pH was decreased. They observed that tissue cells at pH 5 retained mobile 1AA at several times the concentration of the external 1AA. A model for the effect of 1AA on growth of maize coleoptiles was proposed by Darville et al. (1979) and included proton release by 1AA, cell wall structure, and elongation growth.

Maize roots were found to show growth inhibition to applied 1AA until the endogenous concentrration of 1AA was reduced by

exodiffusion so that both root growth and geotropism may interact with the balance of exogenous and endogenous 1AA (Pilet et al., 1979). Use of growth-regulating chemicals on prolific and non-prolific maize plants were found by Sorrells et al. (1978) effect maize ear development. They used the compound N-1-napthylphthalmic acid (NPA) to inhibit auxin translocation. Since the use of NPA significantly increased the total yield of non-prolific cultivars and increased the lower ear grain weight and ear number of all their cultivars, they suggested that 1AA may interact with other hormones in a time-dependent mode for inhibition of lower ear development.

Various cations have been found to alter the auxin activity of 1AA. Evans et al. (1980) reported that when 1AA was present at concentrations that caused inhibition to the elongation of maize roots, the pH of the bathing medium increased sooner than that during a latent period for such inhibition of elongation. They concluded that the cell-wall pH was modified by the 1AA and played a role in the control of root elongation. Under saline conditions, Pandey (1970) noted that, when maize seeds were treated with 0 to 900 ppm in salt solutions of 1000, 2000, and 3000 μmhos/cm, there was a change in amino acid content. As salt concentration was increased, the level of aspartic acid and glutamine decreased. Presence of added 1AA to the seeds resulted in an increase of tyrosine, tryptophan plus valine, alanine, cystine, and arginine in the maize plants. Goring et al. (1979) reported that 1AA application and temporarily-reduced

water potential reacted on the transmembrane potential of maize coleoptile within 15 minutes. This could be explained by 1AA and water stress inducing activation of H^+ secretion by the plasmalemma. Work by Nowakowski (1979) also showed that when maize was grown under conditions of osmotic stress, 1AA oxidase activity was reduced in the roots and shoots. Todor _et al_. (1977) observed that, when Mg deficiency was induced in maize, addition of Mg alone or with 1AA increased biomass accumulation and changed the plant chemical composition. Manganese restored the growth-promoting effect of 1AA and decreased malate dehydrogenase activity of maize in an experiment performed by Kobyl'skaya _et al_. (1976). Phosphorus nutrition of maize was affected by a positive interaction between γ-radiation and the addition of 1AA, Zn, or Mn separately or together (Trifu and Osvath, 1978). With oat (_Avena sativa_ L.) coleoptiles, Rubenstein _et al_. (1979) demonstrated that addition of Ca in the bathing medium stimulated 1AA activity because protons were released from the cell-wall. Maize coleoptile segments under anaerobic conditions showed inhibition of cell enlargement, H^+ extrusion, and K^+ uptake which was attributed to imbalance of 1AA activity (Rasi-Caldogno _et al_., 1978). In another study, Nelles (1977) reported that maize coleoptiles treated for 16 hours with 10^{-5} _M_ 1AA increased in K permeability and decreased in Na permeability. Haschke and Luttge (1978) found that _Avena_ coleoptile segments treated with 1AA exhibited H^+ release by K^+ exchange with a concomitant synthesis of malic acid.

Enzymatic synthesis of lAA from tryptophan was found to be decreased when maize plants were Zn-deficient and was restored rapidly after Zn application (Karakis, 1974).

The binding of auxins to receptor sites of maize tissue was modified by a naturally-occurring compound 6, 7, dimothoxyl-2-benzoxazoline (OMBOA) in a study by Venis and Watson (1978). Other factors affecting the primary root requirement of maize for lAA were reported to be the lAA gradient from shoot to root (Martin et al, 1978), inhibition of lAA activity by red light (Vanderhoef and Briggs, 1978), and polar transport of lAA in vascular tissue of maize (Wangermann and Withers, 1978). Studies by Patel et al. (1978) were conducted using 2-day-old maize seedlings cultured in 10^{-4} ppm of lAA for 24 hours. They reported that the riboxynucleic acid content was increased in elongating cells by the lAA treatment at different phases of elongation. Hall and Bandurski (1978) used ^{14}C-lAA, ^{3}H-lAA, or ^{3}H-tryptophan to trace lAA movement from endosperm of maize to the shoot. Their results showed that lAA can move from endosperm to the shoot at a rate equivalent to that for simple diffusion. However, about 98% of the transported lAA was converted to other compounds during the transport. They concluded that the rate of lAA and tryptophan-derived lAA transport of lAA and active lAA absorption by maize coleoptiles were both found to be temperature dependent and the lAA absorption of ^{14}C-lAA from apically applied donor blocks was a linear function of time in experiments by Naqvi and Gordon (1978). To assist determination of lAA, improvement in

assay procedures for 1AA were developed by Mousdale *et al*. (1980).

Schurzmann and Hild (1980) found that externally applied 1AA and abscisic acid (ABA) on vertical maize roots caused root curvature toward the donor agar block having the 1AA. When the roots were horizontal, 1AA applied on the upper side inhibited or delayed normal geotropic downward bending. The extent of retardation and inhibition of curvature depended on the 1AA concentration in the donor block. Growth or curvature of roots was not affected by ABA in similar experiments. When root tips or coleoptile tips were placed on vertical roots, root curvature was observed.

Lee (1980) sequentially treated stem segments of maize with phenolic substances and 2-^{14}C-1AA. The results suggested that the phenolics also affected the enzymatic oxidation of 1AA *in vivo* in the same way as *in vitro*. Phenolic pretreatment that affected formation of bound 1AA was found to be ferulic acid, coumaric acid, or 4-methylumbelliferone. Compounds which were cofactors of 1AA-oxidase increased the 1AA incorporation while inhibitors of 1AA-oxidase decreased it.

Root segments of maize taken 2 mm long at 1 cm behind the root apex showed stimulation of elongation at pH 4. 1AA decreased elongation at pH 4 but stimulated it at pH 7 after a lag phase (Edwards and Scott, 1974).

In another study by Jacobs and Ray (1976), it was found that auxin induced a decrease in the free space pH within 12 minutes for maize and 30 minutes for pea. There was a corresponding cell elongation at these times. Auxin analogs p-chlorophenoxyisobutyric

and phenylacetic acid did not stimulate elongation or a decrease in pH in the tissue free space. These findings are consistent with the acid secretion theory of auxin action.

Eucalyptus

Classification

Although Eucalyptus forests almost everywhere in Australia look alike, there are about 500 species, subspecies or varieties within the genus (Chippendale, 1973).

The only textbook which deals comprehensively with eucalyptus is that by W. F. Blakely, A Key to the Eucalypts, which was first published in 1934 and later reprinted with some additions by R. D. Johnston in 1955 and with a nomenclature appendix by R. D. Johnston and Rosemary Marryatt in 1965. In the third edition of 1965, 676 species, sub-species, varieties and hybrids are recorded. Excluding the hybrids and doubtful species, and allowing for synonymy resulting from recent investigations, there are 444 separate valid taxa for which descriptions have been published (Chippendale, 1973).

Pryor and Johnson (1971) drew up a classification incorporating the results of more recent study, drawing particularly upon information from the associated disciplines of genetics, ecology, and anatomy, as well as amplifying the study of morphology along traditional lines. In this classification, the genus Eucalyptus is divided into seven subgenera. In turn the subgenera are divided into sections, series, subseries, superspecies, species, and subspecies.

Eucalyptus grandis Hill ex Maiden belongs to the subgenus *Symphyomyrtus* and the section Transversaria (Pryor and Johnson, 1971).

Eucalypts can be either trees or shrubs (Chippendale, 1973). The tallest species is mountain ash (*E. regnams*) from Victoria and Tasmania, recorded to about 98 m. In Western Australia, the tallest species is the karri (*E. diversicolor*) growing to about 76 m. On the other hand, some eucalypt species have a maximum height of 4.5 to 6 m, while some are shrubs only about 2 m high.

E. grandis is a tall straight tree up to 46 m high. The bark is smooth and deciduous, white or subglaucos (Blakely, 1955). Its timber is red, light and durable. The juvenile leaves are opposite for 3 to 4 pairs, shortly petiolate, oblong-lanceolate, thin, undulate, 3 to 6 by 1 to 2.5 cm. The intermediate leaves are alternate, petiolate, broadly lanceolate, slightly undulate, 12 to 18 by 5 to 6 cm. Mature leaves are alternate, petiolate, narrow-lanceolate, acuminate, undulate, 13 to 20 by 2 to 3.5 cm. Venation is moderately fine. Umbels are axillary, 3-to-10-flowered, or more. Peduncles are compressed, 10 to 12 mm long. Buds are pyriform, usually contracted in the middle, pedicellate, glaucous, 10x5 mm. Operculum is conical to shortly rostrate, shorter than the calyx-tube. The name *Eucalyptus* refers to the operculum, being derived from the Greek *eu* = well, and *kalyptos* = covered.

The Eucalypts Range of Growing Conditions

Eucalyptus is by far the most important genus of Australian forest trees. Its members dominate 95% of the Australian forest area and spread out over much of the remainder of the country (Hall *et al*., 1970). A wide variety of hardwood timber is produced from these species; timbers which display a considerable range in characteristics such as color, weight, hardness, toughness, strength, elasticity, durability and fissibility. Because of this diversity of properties, eucalypt timbers have innumerable uses, many being pre-eminent for heavy structural purposes such as bridge building and harbor works.

Apart from the major uses as timber and its derivatives, these trees yield valuable essential oils by foliage distillation, oils that are widely used in pharmacy, perfume manufacture, and industry (Hall *et al*., 1970). Tannins are extracted in commercial quantities from the wood and bark of some species.

Exceptionally hardy species such as some of the snow gums can withstand exposure to high winds, intense cold and heavy snowfalls above 5,000 to 6,000 feet in the Australian Alps and 3,000 feet in the highlands of Tasmania. At the other extreme, in the hot, parched desert and semi-desert regions of the inland, the eucalypts are restricted to watercourses and sheltered depressional areas where sufficient moisture is available to maintain existence during the normally long droughts. Many species exist on less than 250 mm of rain a year (Hall *et al*., 1970).

Eucalypts have been able to adapt themselves to a wide range of conditions in both tropical summer rainfall and cool temperate winter-rainfall areas. They occupy both dry and wet sites, even swamps in places, exposed positions and sheltered congenial slopes and valleys, infertile sands, richer mellow loams and intractable clays (Hall et al., 1970).

Most eucalypt species produce seed prolifically so that, if soil conditions are favorable for germination, an abundant crop of young seedlings is assured to restock whatever blank spaces there may be (Rule, 1967). Apart from these deaths due to overcrowding, bushfires, grazing animals, insects, and fungi take heavy toll of such regrowth right from the start, unless man comes to nature's aid.

One reason why eucalypts have become so popular, for afforestation in other countries where the climate approximates to that of their native habitat, is that they are easy to raise from seed in forest nurseries. Australia relies largely on natural regeneration (seeding from parent trees) wherever possible.

Eucalypts as an Exotic Plant

The story of the cultivation of the eucalypts and the early recognition of their economic possibilities commenced with the establishment of small plantation in southern Europe and North Africa about 100 years ago (Penfold and Willis, 1961). Since then, the ease with which the eucalypts can be cultivated, their rapid growth, and their adaptability, have led to their widespread

introduction into many countries, especially in those which are poorly endowed with forest resources.

Eucalyptus was introduced into California in 1853 (Penfold and Willis, 1961). Later seeds of many species were raised and distributed from 1886 to 1888. Plantations were soon after established in certain areas of California, Arizona, New Mexico, and Florida.

Eucalypt plantations were established in Kenya at the beginning of the twentieth century.

Eucalyptus grandis

E. grandis comes from eastern Australia (FAO Forestry Development Paper, No. 19, 1974). It comes from areas with a rainfall of 900 to 1,270 mm, fairly well distributed throughout the year, but with a marked summer maximum, especially toward the north of its range.

The timber of *E. grandis* is lighter, softer and more fissile than that of most eucalyptus, with moderate strength and durability, prone to warping and other defects especially when sown from young or fast-grown trees (Streets, 1962). The timber quality of fast-grown hybrids between *E. saligna* and *E. grandis* would seem to need examination. Both species and the hybrid make good poles but need preservative treatment for telegraph and transmission poles.

Only small areas of authentic *E. saligna* and *E. grandis* of Australian origin have been planted in savanna conditions (FAO Forestry Development Paper, No. 19, 1974). In trials in Zambia,

it was found that E. saligna was more drought sensitive than E. grandis or E. "grandis" from Africa. (The latter is of mixed origin and the name denotes the common form grown from African seed).

Site Quality

As regards sites, much of the most successful planting of E. "grandis" in Kenya and Malawi has been done at high altitudes outside the savanna region, and in other countries in conditions of rainfall and moisture corresponding to moist high forest types. Phenomenal rates of production have been achieved under such favorable conditions. In Zimbabwe, formerly called Rhodesia, mean annual increments of 61 to 66 m^3/ha have been recorded on the best soils in high rainfall areas (Barrett and Mullin, 1968). This is, however, exceptional. The tree requires good, deep permeable soils and cannot stand poor drainage or water-logging. At the same time, it cannot tolerate drought. A rainfall of 900 mm and upward, with a not too severe dry season, is suitable. In Zambia, where it is the major plantation species, it grows very well on the northern Plateau at elevations of 1,220 m, where it achieves a mean annual top-height increment of 5.1 m and a mean annual diameter increment of 4.2 cm in 2 to 4 years.

E. "grandis" was tried in Congo under a rainfall of 1,200 to 1,300 mm, but with a 4-month dry season. Though it started well, after the first 3 years, its condition deteriorated and this was attributed to shortage of water (Groulez, 1967).

E. "grandis" in its various forms sets seed at an early age. It is relatively easy to handle in the nursery. Seed is sown direct into pots at the rate of 1 g/100 pots. Height growth is rapid and most seedlings reach a height of 30 cm in 10 weeks. In Zambia, smaller plants not more than 23 cm high are preferred. As for all eucalyptus planting, clean site preparation is desirable, and indeed is essential where moisture is likely to be insufficient at any time of the year. Clean weeding is necessary until the canopy has closed enough to suppress grass and invading weeds. The species is susceptible to termite attack and the usual precautions of applying insecticides at the time of planting have to be taken, especially on the drier sites where termite damage is always more severe. It also suffers from die-back on B-deficient soils and, in such cases, application of borate fertilizer may be necessary.

Fertilizers

There is very little information concerning the effect of fertilizers on the growth of eucalypts. From the scattered, rather empirical data that have been collected, it appears that tests with phosphatic fertilizers show little or no effect while nitrogenous fertilizers result, in some cases at least, in quite striking responses (Penfold and Willis, 1961).

Using pot experiments with several species, Beadle (1953) found that added N and phosphate caused increased growth and the production of larger, softer leaves. This indicates that the addition of nitrogenous and phosphatic fertilizers to plantations

established for the production of leaf products, such as essential oils, may increase the overall yield by increasing the amount of leaf material produced per hectare.

Container-Grown Seedlings

Container seedlings and greenhouse production are no longer new concepts in many countries throughout the world. However, major research and development commitments and large investments in production facilities for mass production of container-grown seedlings were made only in the last decade in North America (Stein *et al.*, 1975). The use of container-grown stock varies among regions, because the relative advantage of this more labor-intensive system over the production of bare-root seedlings depends on shock tolerance of the species used, on climate, soil conditions, and on planting methods (Pritchett, 1979).

The reasons or objectives for using container-grown seedlings vary among organizations, but they generally fit into one or more of the following broad categories (Stein *et al.*, 1975).

"1. Meet accelerated demands for nursery stock. Facilities for production of seedlings in containers can be expanded rapidly and seedlings can be produced quickly on more certain, flexible schedules than in bare-root nurseries.

2. Produce some species more readily. For a variety of reasons, certain species are difficult to produce in bare-root nurseries or are particularly sensitive to bare-root handling.

3. Achieve greater production and planting efficiencies. Through use of container-grown seedlings, improvements appear possible in most phases of reforestation. This includes more efficient use and control of genetically improved seed, production of more uniform stock, better protection of seedlings, greater opportunities for mechanization, improved quality and speed of planting, and easier planting among residues or stock.
4. Extend planting seasons. Greater flexibility in production of seedlings and the protection that is provided by the container may permit planting at times when bare-root stock is not available or not properly conditioned. Lengthening the planting season may also permit use of a smaller, or more stable work force.
5. Improve survival and growth of out-planted seedlings. Achieving better survival and growth is a universal goal for everyone who tries new reforestation techniques."

Types of containers

Several types and sizes of containers are commonly used. These may be grouped into three categories: tubes, blocks, and plugs. Tubes can be constructed of either biodegradable or non-degradable plastics, or of kraft or other paper. Tubes require filling with a soil mixture or other growth medium. Some control in the degradation rate of the material from which the tubes are constructed is important to the health of the seedling and for handling purposes (Pritchett, 1979).

Blocks are similar in shape and size to tubes, but they have no outer wall and require no filling. The block is both the container and the planting medium, and seeds are sown directly in the block. The entire package is later transplanted into the soil. They are molded from bonded softwood pulp, polyurethane foam, peat, peat-vermiculite mixtures, or similar materials in which nutrients may be incorporated. Blocks have given excellent results under many conditions, but, unless produced locally, freight cost can be prohibitive (Pritchett, 1979).

Plugs consist of seedlings grown in soil-filled molds, but, unlike tube- or block-grown seedlings, they must be removed from their containers before outplanting. Since the growth medium is bound only by the seedling roots, the plug can be rather fragile and not easily planted by machines.

MATERIAL AND METHODS

Soil Properties

The main coffee-producing areas of Kenya of which Ruiru and Kabete are representative, are located on closely similar soil types, named by Gethin Jones (1949) as the Kikuyu series. These soils are deep, porous and naturally well drained. They are latosols and are derived from a volcanic parent material, tertiary trachytic lava, by weathering *in situ*. They have a high pore space, a fairly high cation exchange capacity and a high clay content, yet the field texture is that of a friable loam (Pereira, 1957). The highly porous surface of the Kabete soil has a good natural crumb structure and it is resistant to erosion. The soil depth may exceed 20 feet on the main ridges and can fall to 2 or less feet on the flanks immediately above the river valleys (Gethin Jones, 1949).

The black cotton soils are also derived from volcanic parent materials of the Tertiary period. The Mwea soil was sampled at the Mwea Plain and the Athi soil was sampled at the Athi Plain. These soils have developed wherever the drainage system was poor.

Kabete soil is dominated by kaolinite and halloysite but Mwea and Athi soils are dominated by montmorillonite which subjects them to extensive swelling and waterlogging during wet seasons and drying and cracking during dry seasons. Other soil properties are shown in a table.

Soil Preparation

One hundred kilograms of each soil sampled at two depths, 0- to 15-cm and 15- to 30-cm, were sent from Kenya. They were air-dired and ground to pass through a 10 mm sieve. Thirty nine 1000-g samples of each soil were weighed into polyethylene bags and placed in plastic pots. A greenhouse experiment was conducted to determine the growth and composition of *E. grandis* when treated with 1AA and three CSP sources at three rates. The CSP sources were: (i) reagent grade monobasic calcium phosphate powder, (ii) pelletized CSP, and (iii) pelletized CSP containing 100 ppm of 1AA. The latter two CSP sources were supplied by the International Fertilizer Development Center (IFDC), Muscel Shoals, Alabama. The supplier stated that the analyses of the materials indicated that the two materials were essentially the same in P_2O_5 content. Both sources contained 15.7% water-soluble P, while source (ii) contained 19.4% citrate-soluble P, and source (iii) contained 19.9% citrate-soluble P. The CSP was applied to give 28, 56, and 112 kg P/ha and the 1AA without CSP was applied to give 0.031, 0.062 and 0.124 kg 1AA/ha, these 1AA concentrations were equivalent to those supplied by the rates of pelletized CSP with 1AA. The CSP treatments were added to the soils in the bags and mixed thoroughly. When 1AA was used alone, 1000 mg were dissolved in alcohol in a liter flask and made to volume with distilled water to give 1000 ppm 1AA. From this, a secondary dilution was prepared and used to give 0.031, 0.062 and 0.124 kg 1AA/ha in triplicate pots of soil. Each such

treatment was thoroughly mixed with the soil after each appropriate quantity of 1AA was added from a dispenser. The soil in each pot was watered to about 75% of its water-holding capacity. The experiment was a completely randomized design.

Eucalyptus Experiment

After the moist soils had equilibrated with the fertilizer treatments for 4 days, six pelletized *E. grandis* seeds were planted in six holes (one in each hole) at about 10 mm depth in each pot and gently covered with loose soil. About 3 weeks after emergence, the seedlings were thinned to three plants in each pot. At 5 weeks after emergence, NH_4NO_3 was added to give 224 kg N/ha. Potassium and zinc sulfates were added at 10 weeks after emergence to give 224 kg K/ha and 44.8 kg Zn/ha. When the plants were about 3 months old, magnesium nitrate was added to give 112 kg Mg/ha. Due to rapid evaporation of water in the greenhouse, it was necessary to flood the pots regularly in order to maintain suitable moisture content for the plants. In the beginning of spring, the temperatures were usually from 27°C to 32°C during the day but were higher towards the end of the season, occasionally reaching about 46°C.

Height measurement of each plant was taken at 2, 3, and 4 months. At the end of 4 months, the plant tops were harvested and stem thickness at the base was measured with a micrometer. The plants were air-dried for a few days and then transferred to a drying room at 60°C. After drying was completed, they were

weighed and milled. Small quantities of leaves of eucalyptus from the top layers of Mwea and Kabete soils were ground separately.

After the eucalyptus harvest, soil samples were taken from the pots, air-dried, and ground in preparation for analysis.

Maize Experiment after Eucalyptus

Maize cultivar 'Pioneer 3160' was planted in the soils after eucalyptus harvest without disturbing the soil. Five seeds were planted in each pot. Because the temperature in the greenhouse was almost always 30°C during the day, the soils in the pots were flooded periodically to ensure optimum moisture content for the plants. About a week after emergence, they were thinned to three plants per pot.

Three weeks after emergence, NH_4NO_3 was added to give 224 kg N/ha and at 4 weeks after emergence $(NH_4)_2SO_4$ was applied to give 224 kg N/ha.

Height measurements were taken at 2, 4, and 6 weeks after emergence. The plants were harvested 6 weeks after emergence, air-dried for 2 days and then transferred to a drying room. After they were completely dry, they were weighed and ground.

After the maize harvest, soil samples were taken from the pots, air-dried, and then ground in preparation for analysis.

Maize Experiment with Two Soils

Athi and Kabete soils from 0- to 15-cm depths, with fresh CSP and 1AA treatments at the same rates as had been used for eucalyptus, were planted with the same above variety of maize

in a separate experiment in the greenhouse. Watering and the temperatures were the same as for the succession experiment. These plants received the same amounts of NH_4NO_3 and $(NH_4)_2SO_4$ as those in the succession experiment at the same time. Height measurements were taken at 2, 4, and 6 weeks after emergence and were harvested after the last height measurement. A single fourth leaf from each pot was put in a separate bag. These were all air-dried for 2 days and then transferred to a drying room. After they were completely dry, they were weighed and ground. The leaf samples which had been put in separate bags were also ground separately. Weights of these latter samples were included with the main weight of the harvested tops.

After the maize harvest, soil samples were taken from the pots, air-dried, and then ground in preparation for analysis. The maize roots were separated from the soils and washed free of soil before drying at about 70°C in an oven for several days. When dry, the roots were weighed and then ground with a small mill.

Analytical Methods

Particle-size analyses on soil samples less than 2 mm were done according to the pipet method as outlined in the Soil Survey Investigations Report No. 1 (1972).

Organic carbon in the soils was determined according to the method of Walkley (1946). Walkley and Black (1934) obtained 60 to 86% recovery of C, for which their multiplying factor was

1.30. Peech et al. (1947) reported a similar multiplying factor of 1.33. In view of their report, a multiplying factor of 1.33 was used in the present study.

Nitrogen in eucalyptus leaves from the top samples (0 to 15 cm) of Mwea and Kabete soils was determined according to the semimicro-Kjeldahl method as outlined in Black (1965).

Soil pH was determined by glass electrode pH meter using a 1:2.5 soil to water ratio, following the procedure outlined by Black (1965).

Reagents for P Determination

Double Acid (DA) reagent. The DA reagent is 0.05 N hydrochloric acid in 0.025 N sulfuric acid. This reagent was prepared by pouring about 15 liters of deionized water into a 20-liter bottle and adding 14 ml of concentrated sulfuric acid and 83 ml of concentrated hydrochloric acid. The volume was made to 20 liters and thoroughly mixed.

Reagent A. Weigh 12 g ammonium molybdate and dissolve in about 400 ml of distilled water. Add 0.2908 g of antimony potassium tartrate and dissolve in 100 ml of distilled water. Both of these dissolved reagents are added to 1000 ml of 5 N H_2SO_4 (148 ml concentrated H_2SO_4 per liter), mixed thoroughly and made to 2 liters. Reagent A was stored in pyrex glass bottle in a dark and cool compartment.

Reagent B. Dissolve 1.056 g of ascorbic acid in 200 ml of reagent A and mix. This reagent was prepared as required, as it does not keep for more than 24 hours (Murphy and Riley, 1962).

Sodium bicarbonate (SB) reagent. This reagent is 0.5 M $NaHCO_3$ solution at pH 8.5. The pH of 0.5 M $NaHCO_3$ was adjusted with 5 M NaOH for 10 liters of the solution which was prepared. The solution was stored in a polyethylene container.

Carbon black. Darco activated charcoal was used.

P standards. Exactly 0.2195 g of oven-dry KH_2PO_4 was dissolved in 500 ml of distilled water and 5 ml of concentrated sulfuric acid were added as a preservative and diluted to 1000 ml in a volumetric flask. This standard was 50 ppm P and was used as needed. A secondary P standard was prepared by pipetting 25 ml of the primary P standard into a 250-ml volumetric flask and was made to volume with DA reagent. This standard contained 5 ppm P and was kept in a refrigerator.

Soil Extraction

In order to use an appropriate DA/soil ratio in the extraction, pH of blank (DA reagent only) was compared with pH of various solution/soil ratios. The solution/soil ratios examined were 10:1, 7:1, and 4:1 employing 50, 35, or 20 ml of DA reagent/5 g soil respectively. The pH of the supernatant after shaking for 30 minutes was measured. The pH of the 10:1 ratio was the closest to that of the reagent.

A 5.0-g sample of each soil sample was weighed into 125-ml extracting bottles and 50 ml of DA reagent were added with an automatic pipette. The bottles were placed in a rack on a mechanical, reciprocating shaker and shaken for 30 minutes.

Sartain _et al_. (1976), working with ten mineral and organic soils from Florida, obtained a curvilinear increase in the quantity of P extracted by DA reagent and 0.03 _N_ NH_4F in 0.05 _N_ HCl with a maximum occurring between 15 and 20 minutes. A longer extracting (shaking) time was chosen for the present study because the soils had a higher clay content. The soils were filtered through Whatman No. 2 filter paper. The filtered extracted solutions were used for elemental analysis.

The 0.5 _M_ $NaHCO_3$ method of Olsen _et al_. (1954) was used with a slight modification. A 2.5-g portion of soil was shaken with 50 ml of the solution for 30 minutes. Activated charcoal (Darco) to remove dissolved organic matter was added and the extract shaken vigorously before filtering through Whatman No. 2 paper. These filtrates were clear.

Extraction of Plant Tissue

Eucalyptus. A 0.50-g sample of ground eucalyptus tops (or leaves) was weighed into crucibles and heated in a muffle furnace for 2 hours at 350°C. Heating was continued at 550°C for 4 hours. The crucibles were allowed to cool. A few drops of distilled water were added to moisten the ash and 5 ml of 40% HCl (2 parts concentrated HCl to 3 parts distilled water) were added and the solution was gently evaporated to dryness on a hot plate in a fume cupboard. The crucibles were washed with 50 ml of _N_ HCl (a little at a time), filtering the washings through Whatman No. 2 paper. The filtrate was collected in bottles and used for elemental analysis.

Maize. A 0.50-g sample of dry maize tops was weighed and heated in a muffle furnace at 350°C for 2 hours. The temperature was raised to 550°C and heating continued for 4 hours. After cooling, the ashed samples were moistened and 5 ml of 40% HCl were added and evaporated to dryness on a hot plate. Due to the presence of black ash, these samples were reheated in the muffle furnace at 350°C for an hour and then at 550°C for 4 hours. After cooling, the ash was moistened with a few drops of distilled water and 5 ml of concentrated HNO_3 were added and evaporated to dryness on hot plates. These residues were washed with 50 ml of N HCl, collecting the filtrate through Whatman No. 2 paper and retained in polyethylene bottles.

A 0.05-g sample of the fourth maize leaves from Athi and Kabete soils (0- to 15-cm depths) were weighed and ashed as the maized tops had been done. A 0.50-g sample of maize roots from these same soils were ashed as above and the ash dissolved in 50 ml of 1 N HCl.

P Determination

Zero, 1, 2, 3, 4, and 5 ml of the 5 ppm P standard were pipetted into 50-ml volumetric flasks. They were filled half-way with distilled water. A few drops of 2,4-dinitrophenol were added followed by 2 N NaOH until a yellow color appeared and N HCl was added drop by drop until the yellow color just disappeared. Then 8 ml of reagent B were added from an automatic dispenser, made to volume with distilled water, and

mixed well. The color was allowed to develop for 20 minutes before being read on a Bausch & Lomb Spectronic 21 at 882 nm. The P concentrations in the standards were 0, 0.10, 0.20, 0.30, 0.40 and 0.50 ppm. The zero P standard was used to set the instrument reading at 0.000 P concentration and 0.50 ppm P standard was used to set the maximum reading 0.500. Suitable aliquots of the soil extracts were taken.

A 1-ml aliquot of the plant extracts was taken for P analysis. Color was developed in the same way as for the standards using the same instrument at 882 nm and the calibrated readings were taken from the instrument.

Calcium, Mg, Cu, Fe, Mn and Zn were determined by atomic absorption spectrophotometry using a Perkin Elmer 5100 instrument and K was determined by emission flame photometry at 769 nm.

Statistical Analysis

All the experiments were completely randomized designs. The computer used for the statistical analysis is an Amdahl V-6-II and IBM 3033 with an OS/MVS Release 3.8 and J 2S2/NJE Release 3.

The analysis was done using an in-house program at the Department of Statistics, University of Florida. The analysis was obtained by converting the factors IAA rate, P source, and P rate to a single factor labeled as treatment, with 13 levels. Single degree of freedom comparisons were then defined based on the original 3 factors. The contrast used and the corresponding treatment are given in the following table.

Treatment comparison		Abbreviation
Linear effect, 1AA alone	1	1AA,L
Quadratic effect, 1AA alone	2	1AA,Q
CSP Powder vs CSP Pellet (Form)	3	CSP form
Linear effect, CSP alone (Rate,Linear)	4	CSP,L
Quadratic effect, CSP alone (Rate, quadratic)	5	CSP,Q
Component Form x Rate interaction	6	Form x rate,L
Component Form x Rate interaction	7	Form x rate,Q
Linear effect, 1AA+CSP pellet	8	CSP·1AA,L
Quadratic effect, 1AA+CSP pellet	9	CSP·1AA,Q
1AA alone vs CSP alone	10	1AA vs CSP alone
1AA+CSP pellet vs 1AA alone, CSP alone	11	CSP·1AA vs CSP+1AA
Control (No 1AA, No CSP) vs others	12	Control vs others

In subsequent tables, the rates were given as r2, r3,....r7, which stand for the rates of 1AA and CSP which were applied, in kg/ha. Thus, for 1AA, terms r2, r3, and r4 represent 0·031, 0·062, and 0·124 kg 1AA/ha, respectively. For CSP, r5, r6, and r7 represent 28, 56, and 112 kg P/ha, respectively.

The abbreviations 1AA, CSP, DA, and SB are used to represent indole acetic acid, concentrated superphosphate, double acid, and sodium bicarbonate, respectively. Phosphorus extracted by DA and SB is termed DA-P and SB-P, respectively.

RESULTS AND DISCUSSION

Eucalyptus Experiment

Soils

Although the soils used in the studies were very similar in pH, Kabete soil had a much higher organic matter content than Athi or Mwea. On the other hand, Mwea soil had a much greater P extractable by double acid (DA-P), being 550 ppm, than either Athi or Kabete each of which had less than 10 ppm P (Table 1). Athi and Mwea soils have more than 50% clay which is mainly montmorillonite. This property made them difficult to water suitably because of the ease of swelling when wet which inhibits water infiltration. Both depths of the Kabete soil have an average of 50% silt and an average of 17% sand. This property, besides its kaolinitic nature, facilitated watering and aeration. Moreover the high percentage of organic matter particularly in the 0- to 15-cm layer of Kabete soil enhanced good crumb structure, a desirable characteristic.

Growth Factors

During the early growth of eucalypt seedlings, there was widespread occurrence of purplish colors on the stems on most plants except those growing on Mwea soil which was very high in P as determined by double acid. The purple (or brown) color was believed to be due to P deficiency. In the later stages of growth (that is about 2 to 3 months), the lower leaves started to lose the green color, becoming yellow and finally red. Addition of magnesium nitrate apparently rectified this problem.

Table 1. Some properties of soils from Kenya.

Analysis	Athi, cm 0-15	Athi, cm 15-30	Mwea, cm 0-15	Mwea, cm 15-30	Kabete, cm 0-15	Kabete, cm 15-30
pH (1:2·5, soil to water)	6.5	6.8	6.3	6.3	6.4	6.4
%C	1.76	1.65	1.69	1.58	7.09	3.34
% sand	12.1	11.6	7.6	7.6	19.7	14.7
% silt	32.4	30.5	25.6	24.4	45.0	55.1
% clay	55.5	58.0	66.8	68.0	35.4	30.2
ppm P by DA method	4.5	5.5	550	550	7.0	1.0

Significant responses to treatments, soils, soil depths, and their interaction with treatment comparisons were obtained (Table 2). At 2 months since emergence, height showed a significant response to CSP form, the means being 18·8 and 16·9 cm, for the powder and pellet forms, respectively (Table 3). This significant difference is substantial on the Kabete soil for which the height for the three rates of CSP powder are approximately double those of the corresponding rates of CSP pellet. There was a linear response of height to CSP form and a quadratic response to P form and rate at 2 months since emergence (Table 2). The height was less where 1AA alone was used compared to that for CSP alone but this effect differed between soils and depths. Growth increase for CSP was 15·9, 7·6, and 6·3 cm for Athi, Mwea, and Kabete soils respectively (Table 4). Depth of soil also influenced the height differences between 1AA and CSP treatments, Table 5, and the difference in height was 8·8 cm for plants on soil from 0 to 15-cm depth compared to an 11·2-cm difference at the 15 to 30-cm depth.

A comparison of CSP+1AA and CSP with 1AA (i.e. CSP·1AA) shows that the height was significantly less for CSP+1AA for Athi and Mwea soils (Table 6). Depth influenced this difference in that the height difference was greater for the 15 to 30-cm depth (5·9 cm) than for the 0 to 15-cm depth (3·3 cm), Table 7. Growth on control treatments was less than on the other treatments (comparison 12) and these differences were influenced by both soils and soil depths, Tables 8 and 9. For Athi and Mwea soils, the height was significantly greater for the other treatments than for the control. However, the

Table 2. Means and significant height responses for <u>Eucalyptus grandis</u> grown on three soils treated with 1AA and CSP.

Factor	Rate	Height, months 2	3	4	No.	Type	Treatment comparisons Height, months 2	3	4
	kg/ha	cm					sum of squares		
Treatment							**	**	**
Control		12.4	25.5	51.7					
1AA	r2	8.3	20.7	53.2	1	1AA,L			
1AA	r3	7.7	21.0	49.7	2	1AA,Q			
1AA	r4	7.6	21.2	50.5	3	CSP form	**		
CSP powder	r5	16.5	32.1	58.1	4	CSP,L	**		
CSP powder	r6	20.0	35.0	62.2	5	CSP,Q			
CSP powder	r7	19.8	33.5	59.9	6	Form x rate,L			
CSP pellet	r5	16.5	31.1	60.1	7	Form x rate,Q	**		
CSP pellet	r6	15.9	30.8	62.3	8	CSP·1AA,L			
CSP pellet	r7	18.3	33.1	61.8	9	CSP·1AA,Q			
CSP·1AA	r2+r5	17.7	33.0	63.2	10	1AA vs CSP	**	**	**
CSP·1AA	r3+r6	17.1	31.1	57.3	11	CSP·1AA vs CSP+1AA	**	**	
CSP·1AA	r4+r7	17.1	32.9	61.0	12	Control vs others	**	**	*
Soils							**	**	**
Athi		15.9	26.9	52.2					
Mwea		18.7	32.8	60.4					
Kabete		10.3	28.3	60.8					
Soils x treatments						as above	**		**
					1				
					2				
					3		**	**	
					4				
					5				
					6				
					7		**		
					8				
					9				
					10		**	**	**
					11		**	**	**
					12		**	**	**

Table 2-continued.

Factor	Rate	Height, months 2	3	4	No.	Type	Treatment comparisons Height, months 2	3	4
	kg/ha		cm				sum of squares		
Depths									
Depths x treatments						as above	**	**	**
					1				
					2				
					3				
					4				
					5				
					6				
					7				**
					8				
					9				
					10		**	**	
					11		**	**	
					12				*

* and ** denote significance at the 0.05 and 0.01 levels, respectively, and the letter L is for linear and Q for quadratic. Rates of 1AA (in text) are expressed progressively as r2, r3, and r4; those for CSP sources are expressed progressively as r5, r6, and r7 (in text).

Table 3. Soil x treatment means for CSP forms x rate quadratic effects found for eucalypt height at 2 months.

P form	P rate	Soil Athi	Mwea	Kabete	Mean
	kg/ha	Means*, cm			
CSP powder					
	28	14.4	20.4	14.6	16.5
	56	22.4	20.7	17.0	20.0
	112	20.6	20.2	18.7	19.8
CSP pellet					
	28	22.1	19.7	7.9	16.2
	56	19.5	20.2	7.9	15.9
	112	23.1	21.1	10.7	18.3

* Difference above 2.3 is significant at the 0.05 level except for mean values.

Table 4. Interaction of soils for 1AA and CSP comparison for eucalypt height at three times.

Treatment*	Athi	Soils Mwea	Kabete	Significant difference
	Mean (cm)			0.05 level
		2 months		1.8
CSP alone	20.3	20.4	12.8	
1AA alone	4.4	12.8	6.5	
Difference	15.9	7.6	6.3	
		3 months		2.4
CSP alone	32.7	34.8	30.4	
1AA alone	11.5	26.8	24.0	
Difference	21.2	8.0	6.4	
		4 months		4.9
CSP alone	58.7	62.3	61.7	
1AA alone	35.7	55.3	61.3	
Difference	23.0	7.0	0.4	

*1AA alone is the mean of treatments 2, 3, and 4 and CSP alone is the mean of treatments 5 through 10.

Table 5. Mean effect of soil depths on eucalypt height in response to 1AA and CSP alone.

Treatment*	Soil depth, cm 0-15	15-30	Significant difference
	Mean, cm		0.05 level
	2 months		1.7
CSP alone	18.6	17.2	
1AA alone	9.8	6.0	
Difference	8.8	11.2	
	3 months		2.4
CSP alone	32.9	32.3	
1AA alone	24.4	17.6	
Difference	8.5	14.7	
	4 months		4.9
CSP alone	60.1	61.4	
1AA alone	53.9	48.4	
Difference	6.2	13.0	

*as in Table 4.

Table 6. Interaction of soils on comparison of mean eucalypt height for CSP with 1AA (CSP·1AA) and CSP+1AA.

Source mean	Athi	Soils Mwea	Kabete	Significant difference
		Mean, cm		0.05 level
		2 months		1.8
CSP·1AA	22.1	21.3	9.8	
CSP+1AA	12.4	16.6	9.7	
Difference	9.7	4.7	0.1	
		3 months		2.4
CSP·1AA	35.4	31.6	28.4	
CSP+1AA	22.1	30.8	27.2	
Difference	13.3	0.8	1.2	
		4 months		4.9
CSP·1AA	60.9	61.9	58.7	
CSP+1AA	47.7	58.8	61.4	
Difference	13.2	3.1	- 2.7	

Table 7. Interaction of soil depths on comparison of mean eucalypt height for CSP·1AA and CSP + 1AA.

Source mean	Soil depth, cm 0-15	15-30	Significant difference
	Mean, cm		0.05 level
	2 months		1.8
CSP·1AA	17.5	17.5	
CSP+1AA	14.2	11.6	
Difference	3.3	5.9	
	3 months		3.4
CSP·1AA	31.1	33.4	
CSP+1AA	28.7	25.0	
Difference	2.4	8.4	
	4 months		6.9
CSP·1AA	59.6	60.9	
CSP+1aa	57.0	54.9	
Difference	2.6	6.0	

Table 8. Mean effect of soils on eucalypt height, comparing controls with the other treatments.

Treatment	Athi	Soils Mwea	Kabete	Significant difference
	Mean, cm			0.05 level
		2 months		1.8
Other treatments	16.7	27.8	10.2	
Control	5.5	18.9	12.6	
Difference	11.2	8.9	- 2.4	
		3 months		2.4
Other treatments	19.2	32.8	28.0	
Control	13.1	32.1	31.1	
Difference	6.1	0.7	- 3.1	
		4 months		8.5
Other treatments	45.2	60.4	52.6	
Control	36.8	59.7	58.7	
Difference	8.4	0.7	- 6.1	

Table 9. Mean effect of soil depth in eucalypt height on control compared to other treatments.

Treatment	Soil depth, cm 0-15	15-30	Significant difference
	Mean, cm		0.05 level
	2 months		1.7
Other treatments	15.9	14.1	
Control	14.4	10.3	
Difference	1.5	3.8	
	3 months		3.4
Other treatments	30.4	28.7	
Control	28.5	22.4	
Difference	1.9	6.3	
	4 months		6.9
Other treatments	58.9	58.0	
Control	57.6	45.8	
Difference	1.3	12.2	

opposite effect was observed in the Kabete soil, in which height of the plants on the controls was significantly greater than for the other treatments. This is really unexpected and is probably due to some other cause such as a more favorable property of Kabete soil (a latosol) compared to the black cotton soils (vertisol), such as higher organic matter and good structure which facilitate water infiltration and aeration. Considering the depths, there was no significant difference in height response to either the control or the other treatments for the 0 to 15-cm depth but the height was significantly greater for the other treatments than for the control treatment in the 15 to 30-cm depth (Table 9).

At 3 months, the height was less where 1AA alone was used compared to that for CSP alone. Growth increase for CSP was 21·2, 8·0, and 6·4 cm for Athi, Mwea, and Kabete soils respectively (Table 4). The differences were significant but alike those at 2 months as presented above. As for the previous month, depth of soil also influenced the height differences between 1AA and CSP treatments, Table 5, and the difference in height was 8·5 cm for plants on soil from 0 to 15-cm depth compared to 14·7-cm difference at the 15 to 30-cm depth. The height was significantly less for CSP+1AA treatment than for CSP·1AA for Athi soil but no significant differences between these treatments were found for the other soils (Table 6). The influence of depth on these treatments, CSP+1AA and CSP·1AA, is that height was significantly greater for CSP·1AA treatment for soil at the 15 to 30 cm depth (Table 7). The height

difference for the 0 to 15 cm depth was 2·4 (which is not significant) and, for the 15 to 30 cm depth, it was 8·4 cm. Growth on control treatment of the Athi soil was significantly less than on the other treatments but greater for Kabete soil, Table 8. The influence of the 15 to 30-cm depth on this was significant, Table 9, but the 0 to 15-cm depth had no significant effect on the controls compared to the other treatments.

At 4 months, there was no significant difference in height between 1AA alone and CSP alone on Kabete soil. In fact the difference that existed before narrowed after 2 months and disappeared at 4 months. However, the plants treated with CSP alone on the Athi and Mwea soils still had significantly greater height than those with 1AA alone. These differences in height were 23 and 7 cm for Athi and Mwea soil respectively. Considering the whole growing period for this study, the height difference between the plants treated with CSP alone and those treated with 1AA alone increased with time while that on Kabete soil narrowed and disappeared at 4 months as already stated above. The CSP alone had a significantly more favorable effect on height at both soil depths than 1AA alone, as was the case previously (Table 5). Like the previous month the height was significantly greater for CSP·1AA treatment than for CSP·1AA on the Athi soil (Table 6). But unlike in the previous months, depth had no significant difference in its influence on these treatments (Table 7). Growth on control treatment of the Athi soil was less than on the other

treatments, though not significantly different. There was no difference in height for this comparison on the Mwea soil (being only 0·7 cm). There was also no significant difference between the control and the other treatments in their effect on height of the plants on Kabete soil (Table 8). However, as was noted above, the plants on the control treatment had greater height on this soil than those on other treatments. Wherever this occurred, the probable cause is depression in growth caused by 1AA which somehow cancelled the expected favorable effect of CSP. The height response of the plants was significantly less for the control than for the other treatments for plants grown on the 15-30 cm depth. The 0-15 cm depth had no influence on these treatment comparisons.

As shown on Table 10, CSP had a significant linear effect on tops P. However, this effect is not clearly presented by Table 11 in which a quadratic effect is suggested by the data for both CSP forms and each of the three soils. There was a significant response of tops P to the lower P rates (28 and 56 kg P/ha) for both CSP powder and CSP pellet (Table 11). At these rates response in tops P was significantly greater for the pellet than the powder form of CSP. Response in tops P was greatest in the Athi soil and least in the Mwea soil, although the latter was much higher than the other two in DA-P.

Stem diameter responded significantly to the form of CSP, soils, depths, and interactions. In all the soils, CSP treatments

Table 10. Means and significant stem diameter, weight of tops, and tops P of Eucalyptus grandis grown on three soils treated with 1AA and CSP.

Factor	Rate	Stem diam.	Tops weight	Tops P	No.	Type	Diam.	Weight	Tops P
						Treatment comparisons			
	kg/ha	mm	g	%			Sum of squares		
Treatments							**	**	**
Control		5.0	17.6	0.072					
1AA	r2	4.3	13.7	0.088	1	1AA,L			
1AA	r3	4.3	13.3	0.087	2	1AA,Q			
1AA	r4	4.4	14.3	0.081	3	CSP form			**
CSP powder	r5	5.7	23.8	0.098	4	CSP,L			**
CSP powder	r6	5.8	24.0	0.136	5	CSP,Q			**
CSP powder	r7	5.5	23.6	0.187	6	Form x rate,L	*		
CSP pellet	r5	5.8	23.7	0.114	7	Form x rate,Q			
CSP pellet	r6	5.4	22.1	0.159	8	CSP·1AA,L			**
CSP pellet	r7	5.7	25.0	0.189	9	CSP·1AA,Q			
CSP·1AA	r2+r5	5.7	22.8	0.112	10	1AA vs CSP	**	**	**
CSP·1AA	r3+r6	5.6	21.7	0.143	11	CSP·1AA vs CSP+1AA	**	**	**
CSP·1AA	r4+r7	5.6	22.4	0.190	12	Control vs others	**	**	**
Soils							**	**	**
Athi		4.8	17.5	0.130					
Mwea		5.5	21.5	0.116					
Kabete		5.5	22.9	0.137					
Soil x treatments						as above	**	**	**
					1				
					2				
					3		*		
					4				*
					5				
					6				
					7				*
					8			*	
					9				
					10		**	**	**
					11		**	**	
					12		**	**	

Table 10-continued.

Factor	Rate	Stem diam.	Tops weight	Tops P	No.	Type	Treatment comparisons Diam.	Weight	TopsP
	kg/ha	mm	g	%			Sum of squares		
Depths							**		**
Depths x treatment						as above	**	**	
					1				
					2				
					3			*	
					4				
					5				
					6				
					7		*	*	
					8				
					9		*		
					10		**		*
					11		**	**	
					12				

* and ** denote significance at the 0.05 and 0.01 levels, respectively, and the letter L is for linear and Q for quadratic. Rates of 1AA (in text) are expressed progressively as r2, r3, and r4; those for CSP sources are expressed progressively as r5, r6, and r7 (in text).

Table 11. Interactions of soils with response of eucalypt tops P to CSP rates.

Soils	P rate, kg/ha 28	56	112
	Mean, %		
		CSP Powder	
Athi	0.099	0.138	0.211
Mwea	0.087	0.127	0.152
Kabete	0.107	0.144	0.197
Mean	0.098	0.136	0.187
		CSP pellet	
Athi	0.104	0.184	0.214
Mwea	0.103	0.136	0.171
Kabete	0.135	0.158	0.184
Mean	0.114	0.159	0.190

caused significantly greater stem growth than the 1AA treatment as shown in Table 12. The greatest difference in stem diameter between these two treatments was 2·6 mm for the plants on the Athi soil although there was no significant difference in stem diameter among the soils treated with CSP. Stem diameter was significantly greater in the CSP-treated soils for the 15- to 30-cm depth than in the same depth of soils treated with 1AA (Table 13). There was no significant interaction for the 0- to 15-cm depth. Stem diameter was significantly less for the CSP+1AA treatment than for CSP·1AA. This interaction was with the Athi soil. There were no significant interactions of Mwea and Kabete soils with CSP·1AA and CSP+1AA treatments with regard to stem diameter (Table 14). Soil depths did not significantly interact with these treatments to show any significant differences in the stem diameter (Table 15). Growth in stem diameter was significantly less for the control than for the other treatments on the Athi soil but had no difference on the other two soils. In fact the plants on control Kabete soil did slightly better than the treated ones (Table 16).

From data which were not tabulated, it was observed that both Athi and Mwea soils had tops weight which decreased with rate of CSP·1AA but which increased for Kabete soil. These effects were significant for Mwea and Kabete soils. CSP treatment caused significant increases in tops weight for all the soils compared with 1AA (Table 12). This effect of CSP is further shown in Table 13 in which this treatment had the same contribution in

Table 12. Interactions for soils with response of eucalypt stem diameter, tops weight, and tops P for comparison of mean CSP and 1AA treatments

Treatment	Soils: Athi	Soils: Mwea	Soils: Kabete	Significant difference
	Mean values			0.05 level
	Stem diameter, mm			0.47
CSP	5.7	5.8	5.7	
1AA	3.1	5.0	5.1	
Difference	2.6	0.8	0.6	
	Tops weight, g			3.1
CSP	22.7	23.1	25.3	
1AA	5.4	16.9	18.9	
Difference	17.3	6.2	6.4	
	Tops P, %			0.019
CSP	0.158	0.129	0.154	
1AA	0.065	0.083	0.105	
Difference	0.093	0.046	0.049	

Table 13. Interactions for soil depths on response of eucalypt stem diameter, tops weight, and tops P for comparison of mean CSP and 1AA treatments.

Treatment	Soil depth, cm: 0-15	Soil depth, cm: 15-30	Significant difference
	Mean values		0.05 level
	Stem diameter, mm		1.2
CSP	5.8	5.7	
1AA	4.7	4.0	
Difference	1.1	1.7	
	Tops weight, g		2.6
CSP	24.4	23.0	
1AA	15.1	12.4	
Difference	9.3	10.6	
	Tops P, %		0.015
CSP	0.152	0.159	
1AA	0.099	0.072	
Difference	0.053	0.087	

Table 14. Interactions of soils with response of eucalypt stem diameter, tops weight, and tops P for comparison of mean CSP, 1AA and CSP plus 1AA treatments.

Treatment	Soils: Athi	Mwea	Kabete	Significant difference
	Means			0.05 level
		Stem diameter, mm		0.47
CSP·1AA	5.7	5.7	5.5	
CSP+1AA	4.4	5.4	5.4	
Difference	1.3	0.3	0.1	
		Tops weight, g		3.1
CSP·1AA	22.6	22.8	21.6	
CSP+1AA	14.1	20.0	22.1	
Difference	8.5	2.8	- 0.5	
		Tops P, %		0.019
CSP·1AA	0.157	0.135	0.153	
CSP+1AA	0.112	0.106	0.150	
Difference	0.045	0.029	0.003	

Table 15. Interactions for soil depths on response of eucalypt stem diameter, tops weight, and tops P for comparison of mean CSP·1AA and CSP plus 1AA treatments.

Treatment	Soil depths 0-15	15-30	Significant difference
	Means		0.05 level
	Stem diameter, mm		1.2
CSP·1AA	5.6	5.7	
CSP+1AA	5.3	4.8	
Difference	0.3	0.9	
	Tops weight, g		2.6
CSP·1AA	21.2	23.4	
CSP+1AA	19.8	17.7	
Difference	1.4	5.7	
	Tops P, %		0.015
CSP·1AA	0.161	0.153	
CSP+1AA	0.125	0.116	
Difference	0.036	0.037	

Table 16. Interaction of soils with response of eucalypt stem diameter, weight of tops, and tops P for comparison of control with other treatments.

Treatment	Soils Athi	 Mwea	 Kabete	Significant difference
	Means			0.05 level
	Stem diameter, mm			0.47
Others	5.0	5.5	5.5	
Control	3.5	5.5	5.9	
Difference	1.5	0.0	- 0.4	
	Tops weight, g			3.1
Others	18.4	21.5	22.8	
Control	7.1	21.6	24.0	
Difference	11.3	- 0.1	- 1.2	
	Tops P, %			0.019
Others	0.136	0.119	0.142	
Control	0.060	0.076	0.080	
Difference	0.076	0.043	0.062	

both soil depths. Yield of the tops was significantly greater for CSP·1AA than for CSP+1AA for the Athi soil. This shows that 1AA depressed yield (Table 14). The tops weight for CSP·1AA was 23·4 g compared to 17·7 g for CSP+1AA for the 15- to 30-cm depth giving a yield difference of 5·7 g; the values for the 0- to 15-cm depth were 21·2 and 19·8 g respectively, giving a yield difference of 1·4 g. The former (5·7 g) was significant (Table 15). Comparison of control and the other treatments for the soils shows that the tops weight for the former were significantly less than those for the other treatments only for Athi soil as shown in Table 16.

The response of tops P was significantly greater for CSP than for 1AA in all the soils as shown in Table 12, an effect which is further shown by both depths in Table 13. The plants on Athi and Mwea soils treated with CSP·1AA had significantly more tops P than the mean for the same soils treated with CSP+1AA, a reflection of some unfavorable, property of 1AA in the latter treatment (Table 14). A similar observation is shown by both depths in Table 15, where tops P is more for the CSP·1AA treatment. The controls in all the soils had significantly less tops P than the other treatments, a reflection of the dominant effect of CSP over 1AA (Table 16).

Both CSP and CSP·1AA had linear effects on leaf P as shown in Table 17 which also shows that leaf P in the plants on the controls was significantly less than leaf P in the plants with the other treatments. This observation can be obtained when the

mean for the controls are compared with that of the other treatments. One unexpected result of this study is that where CSP was applied tops %P was more than for leaf %P. This was unexpected because the tops consist of both leaf and wood, the latter of which should have less P content than the leaf. Tops P for the different CSP forms were higher than leaf P for the same corresponding CSP forms (that is CSP powder, CSP pellet, and CSP·1AA), as shown by Tables 10 and 17, considering the means of each form. However, it should be noted that the interaction of soil with treatments might be a complicating factor for the tops P. There were no soil x treatment or depth x treatment interaction for leaf P.

Athi and Kabete soils greatly responded to CSP and CSP·1AA treatments with all the CSP rates as shown by the data for DA-P in Table 1 when compared to those in Table 18. There really was a negligible response of Mwea soil to these treatments and rates since this soil was very high in DA-P orignially. It was difficult to determine the interaction of the soils on DA-P because of the enormous difference in DA-P between Mwea soil and the other soils. It is doubtful whether it would really be valid to use the data in Table 18 to calculate significant differences since Mwea soil has much higher DA-P than either Athi or Kabete soils. For the same reason, the interaction of soil depth with CSP source (Table 19) may or may not be significant though it is quite clear that there is no significant difference between the powder and the pellet forms in the 15- to 30-cm depth. The data in Table 20

Table 17. Means and significant responses for leaf P (in two soils) of Eucalyptus grandis and soil test P by DA and SB methods for three soils treated with 1AA and CSP.

Factor	Rates	Leaf P	DA P	SB P	Treatment comparisons No.	Type	Leaf P	DA P	SB P
	kg/ha	%	ppm	ppm			Sum of squares		
Treatments							**	**	**
Control		0.094	182	5.6					
1AA	r2	0.107	179	6.3	1	1AA,L			
1AA	r3	0.125	177	6.0	2	1AA,Q			
1AA	r4	0.110	179	6.3	3	CSP form	*	*	
CSP powder	r5	0.091	193	9.7	4	CSP,L	**	**	**
CSP powder	r6	0.112	205	11.7	5	CSP,Q			
CSP powder	r7	0.135	235	24.5	6	Form x rate,L			
CSP pellet	r5	0.111	196	8.4	7	Form x rate,Q			
CSP pellet	r6	0.129	216	14.2	8	CSP·1AA,L	**	**	**
CSP pellet	r7	0.160	243	25.9	9	CSP·1AA,Q			
CSP·1AA	r2+r5	0.115	187	9.3	10	1AA vs CSP		**	**
CSP·1AA	r3+r6	0.123	203	15.4	11	CSP·1AA vs CSP+1AA		*	**
CSP·1AA	r4+r7	0.150	233	23.9	12	Control vs others	**	**	**
Soils							**	**	**
Athi			37.5	12.9					
Mwea		0.113	554						
Kabete		0.133	14.7	17.0					
Soils x treatments						as above		**	
					1				
					2				
					3				
					4			**	
					5				
					6				
					7				
					8			**	
					9				
					10			**	**
					11				
					12				

Table 17-continued.

Factor	Rates	Leaf P	DA P	SB P	Treatment comparisons No.	Type	Leaf P	DA P	SB P
	kg/ha	%	——ppm——				Sum of squares		
Depths						as above		**	**
Soils x treatments					1				
					2				
					3			**	
					4				
					5				
					6				
					7				
					8				
					9			*	*
					10				
					11				
					12				

* and ** denote significance at the 0.05 and 0.01 levels, respectively, and the letter L is for linear and Q for quadratic. Rates of 1AA (in text) are expressed progressively as r2, r3, and r4; those for CSP sources are expressed progressively as r5, r6, and r7 (in text).

Table 18. Interaction of soils on mean DA-P values for linear responses to CSP treatments for eucalypt.

Soils	CSP rates, kg/ha 28	56	112
	Means, ppm		
		CSP only	
Athi	17.4	39.2	90.9
Mwea	556.0	576.0	593.0
Kabete	10.0	20.3	33.0
		CSP·1AA	
Athi	20.0	43.4	91.3
Mwea	530.0	552.0	583.0
Kabete	10.5	15.0	25.5

Table 19. Interaction of soil depth with DA-P extracted from soils for eucalypt for CSP form comparison.

CSP source	Soil depth, cm 0-15	15-30	Difference
	Means, ppm		
Powder	198	224	-26
Pellet	213	223	-10
Differences	- 15	1	

gives a picture similar to that in Tables 1 and 18 for DA-P. The content of DA-extractable P in Mwea soil makes it difficult to evaluate significant differences apart from the fact that this soil is much higher in DA-P than the other soils. Sodium bicarbonate (SB), as expected, extracts less P termed SB-P in most soils than did double acid and this was the case in the present study. However, SB extracted slightly more P from both CSP-treated and 1AA-treated Kabete soil than did DA from the same soil with these treatments (Table 20). On the other hand, DA extracted much more P than SB did from Athi soil treated with CSP and 1AA. This shows that the effectiveness of an extractant is partly influenced by the soil used. It is therefore unwise to generalize on the suitability of the method used as this depends on the soils among other factors.

There was no significant difference between mean leaf N for 1AA and CSP treatments. Leaf N was 1·27% and 1·22% for these treatments respectively. For the soils, mean leaf N was 1·14% and 1·22% for Mwea and Kabete respectively. Thus, there was very little variation in leaf N between treatments (and also between the soils). These results might have been expected because a lot of N fertilizers had been applied.

Maize Experiment after Eucalypt

Growth Factors

At 2 weeks maize height did not show any interaction with soils and treatment and there was no interaction with depths and treatments, but there was a significant difference between the height for 1AA

Table 20. Interaction of soils on DA-P and SB-P for treatment comparison of CSP with 1AA for soils used for eucalypt.

Factor	Athi	Mwea	Kabete	Mean value
		Mean, ppm		
		DA-P		
CSP	49.2	575.2	19.4	214.6
1AA	9.7	517.8	6.2	177.9
Difference	39.5	57.4	13.2	36.7
		SB-P		
CSP	10.2		21.3	10.8
1AA	3.1		9.3	6.2
Difference	7.1		12.0	

alone (41·0 cm) and that for CSP alone (39·0 cm) as shown in Table 21. This is the opposite of what was found for eucalypt at 2 months. This comparison with eucalypt may be invalid due to the difference in age of the two plants. It is very likely that, at 2 weeks, maize plants use very little P so that even if a large amount of this nutrient is present in soil, such young plants need or use little of it. This explanation may apply in a similar way to the significant difference between height of maize at 2 weeks for CSP·1AA treatment (38·1 cm) compared to CSP+1AA treatment (40·0) at that age.

The maize on the Athi, Mwea, and Kabete soils had a mean height of 33·7, 35·2, and 48·1 respectively, (for treatments 5 through 10) at 2 weeks. The plants responded better to the Kabete soil. At 2 weeks, height for maize was 40.9 cm for 0- to 15-cm depth and 37·8 cm for 15- to 30-cm depth but this difference was not significant.

At 4 weeks since emergence, CSP rates caused significant linear effects on height (Table 21 and 22) and the mean height for Kabete soil was significantly higher than for the other soils for all the CSP rates. There were similar linear height responses to CSP·1AA rates for the soils (Table 21 and 23). Again, the mean height for Kabete soil was significantly greater than for the other soil for all the CSP·1AA rates. From these observations, it is quite clear that both CSP and CSP·1AA had similar effects on maize height at 4 weeks. Furthermore, height had an interaction

Table 21. Means and height of Zea mays responses to residual 1AA and CSP applied to three soils.

Factor	Rate	Height, weeks 2	4	6	Treatment comparisons No.	Type	Height, weeks 2	4	6
		cm					Sum of squares		
Treatments	kg/ha							**	**
Control		39.7	69.1	92.7					
1AA	r2	41.0	69.4	90.3	1	1AA,L			
1AA	r3	41.3	68.8	90.6	2	1AA,Q			
1AA	r4	41.0	69.2	91.3	3	CSP form			
CSP powder	r5	39.1	72.7	100.1	4	CSP,L		*	**
CSP powder	r6	39.7	75.2	104.2	5	CSP,Q			
CSP powder	r7	39.1	74.5	104.5	6	Form x rate,L			
CSP pellet	r5	39.2	72.6	100.3	7	Form x rate,Q			
CSP pellet	r6	38.4	74.2	105.3	8	CSP·1AA,L		**	**
CSP pellet	r7	38.7	76.7	107.8	9	CSP·1AA,Q			
CSP·1AA	r2+r5	36.7	71.0	100.6	10	1AA vs CSP alone	*	**	**
CSP·1AA	r3+r6	39.5	74.9	103.7	11	CSP·1AA vs CSP+1AA	*		**
CSP·1AA	r4+r7	38.1	76.7	108.9	12	Control vs others		**	**
Soils (Treatments 5 to 10 only)							**	**	**
Athi		33.7	68.4	100.3					
Mwea		35.2	68.0	101.4					
Kabete		48.1	86.6	109.4					
Soils x treatments						as above		**	**
					1				
					2				
					3				
					4			*	
					5				
					6				
					7				
					8			**	
					9				
					10			**	**
					11				
					12				**

Table 21-continued.

Factor	Rate	Height, weeks 2	4	6	No.	Type	Treatment comparisons Height, weeks 2	4	6
		—— cm ——					Sum of squares		
Depths							**	**	**
Soil depths x treatments									*
					1				
					2				
					3				
					4				
					5				
					6				
					7				
					8				**
					9			**	
					10				*
					11			*	
					12				

* and ** denote significance at the 0.05 and 0.01 levels, respectively, and the letter L is for linear and Q for quadratic. Rates of lAA (in text) are expressed progressively as r2, r3, and r4; those for CSP sources are expressed progressively as r5, r6, and r7 (in text).

Table 22. Interaction of soils with maize height at 4 weeks for comparison of linear response to CSP rates.

Soils	CSP rates, kg/ha† 28	56	112	Mean
	Means, cm			
Athi	67.9	70.2	66.5	68.4
Mwea	67.7	67.1	68.7	68.0
Kabete	82.1	86.9	91.0	86.6

†Significant difference between treatments (0.05 level) is 6.6 cm.

Table 23. Interaction of soils with maize height at 4 weeks for comparison of linear response to CSP·1AA rates.

Soils	CSP·1AA rates, kg/ha 28	56	112	Mean	Significant difference
	Means, cm			cm	0.05 level
Athi	64.7	71.5	69.2	68.5	6.6
Mwea	67.2	68.8	67.1	67.7	
Kabete	80.9	84.3	94.0	86.4	
Mean	70.9	74.9	76.8		

Table 24. Interaction of soils with maize height at 4 weeks for comparison of response to CSP and 1AA alone.

Soils	Treatment means CSP	1AA	Difference	Significant difference
	Means, cm			0.05 level
				4.2
Athi	68.4	65.1	3.3	
Mwea	68.0	68.6	- 0.3	
Kabete	86.6	73.7	12.9	

with soil depth due to CSP·1AA (Table 21); the response was quadratic. The height was less where 1AA alone was used in the Kabete soil than where CSP alone was used, but there was no difference between these treatments for each of the other soils. Each of the treatments CSP·1AA and CSP+1AA was 78·2 cm at 0- to 15-cm depth and 69·5 cm at 15- to 30-cm depth compared to values of 78·5 and 66·7 cm, respectively, for CSP+1AA; the significant difference for this comparison was 6·6. It is clear that growth was better in the 0- to 15-cm depth. The mean height for the plants in the control was 69·1 compared to 73·0 cm for the other treatments and the mean height for Athi, Mwea, and Kabete, was 68·4, 68·0, and 86·6 cm, respectively, considering treatments 5 through 10, in Table 21. The mean height for 0- to 15-cm depth was 79·1 compared to 67·3 for the 15- to 30-cm depth, an indication of better growth in the top soil.

At 6 weeks after emergence, CSP pellet had a significant linear effect on height and CSP powder had no such effect. The mean height for the CSP powder corresponding to increasing rates were 100·1, 104·2, and 104·5 cm and those for CSP pellet were 100·3, 105·3, and 107·8. For a significant difference of 5·6, it is clear that there were no significant differences among the rates for CSP powder. These data are presented in Table 21 except for the above significant difference. The CSP·1AA also had a significant linear effect on height for which the means are 100·6, 103·7, and 108·7 (5·6 being the significant difference as

above). There were significant interactions of all CSP·1AA rates with depths as shown in Table 25. In every case, there was greater height in the 0- to 15-cm depth than in the lower depth. A comparison of CSP with 1AA treatments alone shows that height was greater for CSP in all the soils (Table 26). The height differences between these treatments were significant for two soils Athi and Kabete, being 16·8 and 17·6, respectively. The corresponding difference for Mwea soil was 6·3. Lack of significance for this soil is most likely due to a high level of P present. At 6 weeks since emergence, the mean height for CSP·1AA was significantly better than that for CSP+1AA, being 104·3 and 99·4 cm respectively (Table 21). This difference is probably due to low values for 1AA which depressed growth. Mean height for the control was 92·7 cm compared with 100·6 cm for the other treatment. The difference must be due to the positive effect of CSP on growth which also overcame the adverse effect of 1AA alone. As for the previous weeks, there was better growth in height for the 0- to 15-cm depth than in the lower depth (107·7 and 92·4 cm, respectively).

As shown in Tables 27 and 28, there was an interaction of soils with weight of maize tops due to CSP forms used. Tops weight for the pellet form was greater than that for CSP as powder in the case of Kabete soil but the corresponding differences for Athi and Mwea soils were not significant. Tops weight for Kabete soil was almost twice as large as for each of the other soils, comparing values corresponding to each of the CSP forms. There were

Table 25. Interaction of soil depths on maize height at 6 weeks comparing linear response to CSP·1AA rates.

Soil depth	CSP·1AA rates, kg/ha 28	56	112	Significant difference
cm	Mean, cm			0.05 level
0-15	111.0	110.0	111.6	13.0
15-30	84.2	81.3	80.9	
Difference	26.8	28.7	30.7	

Table 26. Interaction of soils on maize height at 6 weeks comparing CSP with 1AA treatments alone.

Soils	Treatments CSP	1AA	Difference	Significant difference
	Means, cm			0.05 level 13.0
Athi	100.3	83.5	16.8	
Mwea	102.9	96.6	6.3	
Kabete	109.9	92.3	17.6	

Table 27. Means and responses of tops weight and tops P of *Zea mays* and of soil test (DA) P to residual 1AA and CSP treatments of three soils.

Factor	Rate	Tops weight	Tops P	DA P	No.	Type	Treatment comparisons: Tops weight	Tops P	DA P
	kg/ha	g	%	ppm			Sum of squares		
Treatments							**	*	**
Control		9·7	0·095	158·5					
1AA	r2	10·3	0·095	160·1	1	1AA,L			
1AA	r3	9·8	0·095	162·0	2	1AA,Q			
1AA	r4	10·3	0·095	153·5	3	CSP form	**		
CSP powder	r5	12·0	0·106	170·7	4	CSP,L	**	**	**
CSP powder	r6	14·4	0·120	183·1	5	CSP,Q			
CSP powder	r7	16·5	0·143	204·9	6	Form x rate,L			
CSP pellet	r5	13·3	0·109	174·1	7	Form x rate,Q			
CSP pellet	r6	14·4	0·133	199·0	8	CSP·1AA,L	**	*	**
CSP pellet	r7	18·4	0·153	213·6	9	CSP·1AA,Q			
CSP·1AA	r2+r5	12·5	0·114	181·7	10	1AA vs CSP alone	**	**	**
CSP·1AA	r3+r6	14·5	0·129	199·1	11	CSP·1AA vs CSP+1AA	**	*	**
CSP·1AA	r4+r7	17·5	0·161	212·2	12	Control vs others	**	*	**
Soils (Treatments 5 to 10 only)							**	**	**
Athi		11·2	0·127	31·8					
Mwea		11·9	0·169	528·1					
Kabete		21·4	0·087	12·6					
Soils x treatments							**	**	**
						as above			
					1				
					2				
					3		**		
					4		**	**	**
					5				*
					6				
					7				
					8		**	**	
					9				
					10		**	**	**
					11		**		**
					12		**		*

Table 27-continued.

Factor	Rate	Tops weight	Tops P	DA P	No.	Type	Treatment comparisons Tops weight	Tops P	DA P
Depths	kg/ha	g	%	ppm			Sum of squares		
Soil depths x treatments						as above			
					1				
					2				
					3				*
					4				
					5				
					6				*
					7				
					8				
					9				
					10				
					11				
					12				

* and ** denote significance at the 0·05 and 0·01 levels, respectively, and the letter L is for linear and Q for quadratic. Rates of 1AA (in text) are expressed progressively as r2, r3, and r4; those for CSP sources are expressed progressively as r5, r6, and r7 (in text).

Table 28. Interaction of soils with maize tops weight for comparison of CSP forms.

Soils	CSP sources Powder	Pellet	Difference	Significant difference
	Means, g			0.05 level 0.96
Athi	11.1	11.3	- 0.2	
Mwea	12.2	11.6	0.6	
Kabete	21.8	23.3	- 1.5	

Table 29. Interaction of soils with maize tops weight, tops P, and DA-P for comparison of linear effect of CSP rates.

Soils	CSP rates, kg/ha 28	56	112	Significant difference
	Means Tops weight, g			0.05 level 2.4
Athi	9.5	11.5	12.7	
Mwea	12.0	11.1	12.7	
Kabete	16.7	20.2	27.0	
	Tops P, %			0.014
Athi	0.100	0.122	0.160	
Mwea	0.145	0.174	0.186	
Kabete	0.078	0.086	0.099	
	DA-P, ppm			21.0
Athi	16.7	18.9	64.7	
Mwea	498.0	542.0	544.0	
Kabete	6.4	11.6	19.9	

significant linear effects of CSP rates on tops weight for Athi and Kabete soils, the latter being more significant (Table 29). Growth corresponding to each CSP rate was better in Kabete soil than in the other soils. The rates of CSP·1AA had linear interaction with tops weight in a way very similar to that of SCP rates (Table 30). As had been observed earlier in this discussion, growth was found to be better in all the soils treated with CSP than in those treated with 1AA alone as the tops weight show in Table 31. Tops weight for CSP·1AA was larger than that for CSP+1AA in Kabete soil but the reverse was true for Mwea soil. This suggests that growth depression by 1AA alone (as far as tops weight for maize was concerned) was not as apparent in Mwea soil which was high in DA-P as it was in the other soils with low DA-P. Tops weight for CSP·1AA was not significantly different from that for CSP+1AA in Athi soil (Table 32). It is shown in Table 33 that there was better growth for both control and the other treatments in Kabete soil than for these treatments in Athi and Mwea soils. Furthermore, it is shown that growth was less in the controls of Athi and Kabete soils than in the same soils with the other treatments.

Although Mwea soil had a much higher DA-P, the mean tops weight for this soil was not different from that for Athi soil and was even lower than the mean tops weight for Kabete soil. The mean values for treatments 5 through 10 are shown in Table 27. There was better growth in the 0- to 15-cm depth than in the lower depth. For these, the tops weight was 17·06 and 9·68 g respectively.

The CSP rates had significant linear effects on tops P for the soils as shown in Tables 27 and 29. Although Table 29 shows that tops P for Kabete soil was less than for Athi and Mwea soils, caution should be exercised in their interpretation because of the differences in tops weight. Instead total uptake of P should be considered. The CSP·1AA rates had linear effect on tops P, similar to CSP rates (Table 30). As expected for all the soils, tops P was greater for CSP treatment than for 1AA alone (Table 31). There was a slight difference between tops P for CSP·1AA (0.135%) and that for CSP+1AA (0.117%) as shown in Table 27. Tops P for the controls for all the soils were significantly less than those for the other treatments. This was expected because the controls had no P treatment, an obvious requirement. Mean tops P for the control was 0.097% compared to 0.130% for the other treatments. Tops P for the soils as shown in Table 27 only give a partial picture because tops weight should be considered in interpreting them (tops weight were not the same between the soils). Tops P for the depths were 0.117% and 0.121% for 0- to 15-cm and 15- to 30-cm depths, respectively.

It is shown in Table 27 that CSP rates had significant linear effects of DA-P for all the soils and the DA-P means for each rate and for each soil are shown in Table 29, which indicates significant differences among the rates for each of Athi and Mwea soil. Validity of the interpretation of the data for DA-P is complicated by the fact that Mwea soil had much higher P than the other soils. Because of this, the value to be used to determine

Table 30. Interaction of soils on maize tops weight, tops P, and DA-P for linear response to CSP·1AA rates.

Soils	CSP·1AA rates, kg/ha 28	56	112	Significant difference
		Means		0.05 level
		Tops weight, g		2.4
Athi	8.8	12.5	12.0	
Mwea	10.9	11.2	12.0	
Kabete	17.9	20.0	28.5	
		Tops P, %		0.014
Athi	0.103	0.121	0.173	
Mwea	0.157	0.176	1.201	
Kabete	0.082	0.089	0.108	
		DA-P, ppm		21.0
Athi	13.6	20.4	59.4	
Mwea	524.0	568.0	556.0	
Kabete	7.5	8.9	21.4	

Table 31. Interaction of soils on maize tops weight, tops P, and DA-P for comparison of CSP and 1AA alone.

Soils	Treatment comparison CSP	1AA	Difference	Significant difference
	Mean			0.05 level
				2.4
		Tops weight, g		
Athi	11.2	6.5	5.7	
Mwea	16.9	11.1	5.8	
Kabete	17.8	11.4	6.4	
		Tops P, %		0.014
Athi	0.127	0.073	0.054	
Mwea	0.168	0.136	0.032	
Kabete	0.088	0.074	0.014	
		DA-P, ppm		21.0
Athi	31.7	4.9	26.8	
Mwea	528.0	466.0	52.0	
Kabete	12.6	4.3	8.3	

Table 32. Interaction of soils on maize tops weight, and DA-P for comparison of CSP·1AA and CSP+1AA treatments.

Soils	Treatment comparison CSP·1AA	CSP+1AA	Difference	Significant difference
	——— Means ———			0.05 level
	Tops weight, g			2.4
Athi	11.1	8.9	2.2	
Mwea	11.4	14.0	- 2.6	
Kabete	22.1	14.6	7.5	
	DA-P, ppm			21
Athi	31.1	18.3	12.8	
Mwea	549.0	497.0	52.0	
Kabete	12.6	8.5	4.1	

Table 33. Interaction of soils on maize top weight, tops P, and DA-P for comparison of control with the other treatments.

Soils	Treatment comparison Others	Control	Difference	Significant difference
	——— Means ———			
	Tops weight, g			2.4
Athi	10.0	6.3	3.7	
Mwea	11.6	10.4	1.2	
Kabete	19.5	12.4	7.1	
	Tops P, %			0.014
Athi	0.117	0.078	0.049	
Mwea	0.163	0.136	0.027	
Kabete	0.085	0.070	0.015	
	DA-P, ppm			21.0
Athi	24.8	6.7	18.1	
Mwea	520.0	465.0	55.0	
Kabete	10.5	4.4	6.1	

Table 34. Interaction of soil depths on DA-P extracted for comparison of CSP forms.

Soil depth	CSP forms Powder	Pellet	Difference	Significant difference
cm	Means			0.04 level
0-15	173	194	-21	17
15-30	200	197	3	

Table 35. Interaction of soil depths on DA-P extracted for comparison of linear response to CSP forms.

Soil depth	P rate, kg/ha 28	56	112	Significant difference
	Means			0.05 level
	CSP powder, ppm			21
0-15	160	174	185	
15-30	182	192	225	
	CSP pellet, ppm			
0-15	161	204	217	
15-30	187	193	210	

whether there are significant differences may be improperly too large for Athi and Kabete soils. The CSP·1AA rates had a linear effect on DA-P values which were very similar to those of CSP rates (compare data for DA-P in Tables 29 and 30). As expected, DA-P values from the soils treated with CSP were higher than those treated with 1AA alone (Table 31). Again, interpretation is complicated by the much larger DA-P in Mwea soils compared with the other soils. The inclusion of 1AA alone in CSP+1AA treatment lowered DA-P in all the soils compared to CSP·1AA in the same soils (Table 32). Both these treatments indicated that Athi soil had much higher amounts of DA-P than Kabete soil with the same treatments. The DA-P in the controls was less than in the other treatments as the data in Table 33 shows. There is a close relationship between the DA-P data in Table 33 and those in Table 31 and 32 because of the similar treatments used.

There was a slight interaction between depths and CSP forms on DA-P extracted (Table 34). Apparently, presence of CSP pellets contributed more to DA-extractable P in the 0- to 15-cm depth than did the CSP powder. However, little or no significance can be attached to this observation because the means were based on soils vastly differing in DA-P, that is, Mwea on the one hand compared with Athi and Kabete on the other. The same reasoning should apply to the data in Table 35 which takes into account the rates and forms of CSP used. Apparently, there were linear responses of DA-P to CSP rates at both depths.

Maize Experiment with Two Soils, Athi and Kabete, Treated with Fresh CSP and 1AA

Growth Factors

At 2 weeks since emergence height response of maize to CSP alone was significantly better than for 1AA, being 46·0 and 40·4 cm respectively (Table 36). The opposite of this had been found for residual CSP and 1AA for maize in the previous experiment after eucalpyt harvest. The probable explanation is that in the present study with the two soils, Athi and Kabete, the treatments were more recent so that CSP was more effective in promoting growth, while 1AA depressed growth. The mean height for Kabete soil was greater than that for Athi soil (48·2 and 43·9 cm) respectively. There were no interactions with soils at 2 weeks.

At 4 weeks since emergence, height responded linearly to CSP rates, being 92·5, 92·5 and 98·8 cm, as shown in Table 36. Residual CSP had similar linear effects in the previous maize experiment. As before, height of the plants on Kabete soil were significantly greater than that of the Athi soil. Also as previously found in the other maize experiment and at 2 weeks in the present study, height response to CSP was significantly better than response to 1AA, being 94·6 cm for the former compared to 75·6 cm for 1AA. However, growth was significantly better in Kabete soil than in Athi soil for both CSP and 1AA treatments (Table 37). The mean height corresponding to CSP·1AA was 94·4 cm, very similar to that for CSP alone, and the mean height for CSP+1AA was 88·3 cm, higher than 75·6 for 1AA alone. The difference in the value corresponding to CSP+1AA and 1AA alone is undoubtedly due to the fact that CSP

Table 36. Means and significant responses for Zea mays height during 6 weeks grown on two soils treated with 1AA and CSP.

Factor	Rate	Height 2 weeks	Height 4 weeks	Height 6 weeks	Comparison No.	Comparison Type	Treatment comparison 2 weeks	Treatment comparison 4 weeks	Treatment comparison 6 weeks
		—— Mean, cm ——					Sum of squares		
Treatment	kg/ha						*	**	**
Control		38.7	75.6	100.0					
1AA	r2	39.9	76.6	101.6	1	1AA,L			
1AA	r3	40.0	75.3	97.8	2	1AA,Q			
1AA	r4	41.3	75.0	97.4	3	CSP form			
CSP powder	r5	45.9	91.0	118.1	4	CSP,L		**	*
CSP powder	r6	45.5	92.0	120.6	5	CSP,Q			
CSP powder	r7	50.1	100.0	126.7	6	Form x rate,L			
CSP pellet	r5	45.9	93.9	121.6	7	Form x rate,Q			
CSP pellet	r6	40.0	92.9	119.6	8	CSP·1AA,L			
CSP pellet	r7	49.0	97.6	124.1	9	CSP·1AA,Q			
CSP·1AA	r2+r5	49.4	92.9	121.5	10	1AA vs CSP	**	**	**
CSP·1AA	r3+r6	46.1	95.1	122.6	11	CSP·1AA vs CSP+1AA		**	**
CSP·1AA	r4+r7	43.8	95.2	121.3	12	Control vs others		**	**
Soils (Treatment 5 to 10 only)							**	**	**
Athi		43.9	86.6	111.0					
Kabete		48.2	102.6	132.6					
Treatments x soils						as above			**
					1				
					2				
					3				
					4				
					5				
					6				
					7				
					8				
					9				
					10			**	**
					11				
					12				

* and ** denote significance at the 0·05 and 0·01 levels, respectively, and the letter L is for linear and Q for quadratic. Rates of 1AA (in text) are expressed progressively as r2, r3, and r4; those for CSP sources are expressed progressively as r5, r6, and r7 (in text).

in CSP+1AA treatment partially offset the unfavorable effect of 1AA alone. The difference in mean height for CSP·1AA compared to CSP+1AA was significant. Difference in mean height for the control compared to the other treatments was significant (75·6 and 87·5 cm respectively). This simply means that CSP in the other treatments favored growth as expected.

As for the previous weeks, there were significant height responses, at 6 weeks since emergence, to CSP rates. The means were 119·8, 120·1, and 125·4 cm. There were interactions of the soils on height for comparison of CSP and 1AA treatments alone similar to those at 4 weeks as shown in Table 37. The effects of CSP·1AA and CSP+1AA were as significant at 6 weeks as they had been at 4 weeks, the only difference being greater height at 6 weeks with 121·8 cm for CSP·1AA and 114·2 for CSP+1AA. The difference between these height means was significant. Furthermore, there was better growth in the other treatments compared to growth in the controls, 123·6 and 100·0 cm, respectively. The mean height for Athi (111·0 cm) was less than that for Kabete (132·6 cm) at 6 weeks, considering treatments 5 to 10 only (Table 36).

There were significant linear effects of CSP rates to tops yield of maize on Kabete soil (Table 39). The CSP powder gave a quadratic effect on tops yield and the pellet form did not. Tops yield for powder were 25·7, 27·6, and 32·4 g compared with 25·2, 30·7, and 33·1 g for the pellet form. There was less tops yield for 1AA (14·2 g) than for CSP alone (29·1), quite a significant difference. Apparently, 1AA had the same effect on yield as it had

Table 37. Interaction of soils on maize height at 4 and 6 weeks for comparison of CSP to 1AA treatments alone.

Soils	Treatment CSP	Treatment 1AA	Difference	Significant difference
	—— Mean, cm	——	cm	0.05 level
	4 weeks			6.8
Athi	86.6	61.3	25.3	
Kabete	102.6	90.2	12.4	
	6 weeks			
Athi	111.0	75.9	35.1	
Kabete	132.6	122.3	10.3	

on height, while CSP had the opposite and favorable effects. The mean tops yield for CSP·1AA was 29·9 g and that for CSP+1AA was 24·1 g, giving a picture very similar to that found between these sources for mean height. This difference was siginficant. Mean yield for the control was 12·2 g compared to 25·6 g for the other treatments. Thus, growth in the untreated soils was much less than for the other treatments.

The CSP rates had significant linear effects on tops P (Tables 38 and 39). Though Kabete soil had lower tops P than did Athi soil, the real situation in terms of total P uptake must be different because tops yield for Kabete soil > tops yield for Athi soil (Table 39). Similarly, CSP·1AA rates had significant linear effects on tops P for both soils as shown in Table 40. The P content of the tops showed a greater difference between tops P from CSP treatment than 1AA treatment of Athi soils than that between the same treatments for Kabete soil. The differences were 0·097 and 0·031 %P, respectively (Table 41). This might simply reflect the fact that maize exhibited better P uptake on Kabete soil treated with 1AA than in the other soils with the same treatment. This was also true for eucalypt. Tops P for CSP·1AA treatment was significantly greater than that for CSP+1AA (0·146 and 0·111 %P respectively) because of inclusion of 1AA treatment alone in the latter. In both Athi and Kabete soils, there was significantly less tops P in the controls than in the other treatments.

Table 38. Means and significant yield and tissue P responses for Zea mays grown on two soils treated with 1AA and CSP.

Factor	Rate	Tops yield	Tops P	Leaf P	Treatment comparison No.	Type	Yield	Tops P	Leaf P
		g	%	%			Sum of squares		
Treatment, kg/ha							**	**	**
Control		12.2	0.086	0.072					
1AA	r2	14.8	0.081	0.061	1	1AA,L			
1AA	r3	14.9	0.084	0.065	2	1AA,Q			
1AA	r4	12.8	0.088	0.078	3	CSP form			
CSP powder	r5	25.7	0.103	0.067	4	CSP,L	**	**	**
CSP powder	r6	27.6	0.134	0.096	5	CSP,Q			
CSP powder	r7	32.4	0.197	0.144	6	Form x rate,L			
CSP pellet	r5	25.2	0.111	0.082	7	Form x rate,Q	*		
CSP pellet	r6	30.7	0.141	0.111	8	CSP·1AA,L		**	**
CSP pellet	r7	33.1	0.200	0.129	9	CSP·1AA,Q			
CSP·1AA	r2+r5	26.8	0.103	0.074	10	1AA vs CSP	**	**	**
CSP·1AA	r3+r6	30.9	0.135	0.103	11	CSP·1AA vs CSP+1AA	**	**	
CSP·1AA	r4+r7	31.9	0.199	0.116	12	Control vs others	*	**	*
Soils (Treatments 5 to 10 only)							**		
Athi		20.8	0.170	0.112					
Kabete		37.5	0.126	0.098					
Treatment x soils						as above	*	**	*
					1				
					2				
					3				*
					4		**	**	
					5				
					6			**	
					7				
					8			**	
					9				
					10			**	
					11				
					12			**	

* and ** denote significance at the 0.05 and 0.01 level, respectively, and the letters L and Q stand for linear and quadratic, respectively. Rates of 1AA (in text) are expressed progressively as r2, r3, and r4; those for CSP sources are expressed progressively as r5, r6, and r7 (in text).

Table 39. Interaction of soils on maize tops yield and tops P for comparison of linear effect of CSP rates.

Soils	CSP rate, kg/ha 28	56	112	Significant difference
	Mean			0.05 level
	Tops yield, g			4.5
Athi	18.9	21.4	21.9	
Kabete	32.0	37.0	42.6	
	Tops P, %			0.018
Athi	0.112	0.152	0.245	
Kabete	0.103	0.125	0.153	

Table 40. Interaction of soils on maize tops P for comparison of linear effect of CSP·1AA rates.

Soils	CSP·1AA rates, kg/ha 28	56	112	Significant difference
	%			0.05 level 0.018
Athi	0.104	0.155	0.234	
Kabete	0.101	0.116	0.164	

Table 41. Interaction of soils on maize tops P for comparison of CSP and 1AA treatments.

Soils	Treatments CSP	1AA	Difference	Significant difference
	%			0.05 level
Athi	0.170	0.073	0.097	0.018
Kabete	0.127	0.096	0.031	

As for tops yield and tops P CSP rates had significant linear effects on leaf P (Table 38). A comparison of CSP forms shows an interaction of soils on maize leaf P (Table 43). There is no difference between sources but only between soils for CSP powder. Similar in effect to CSP, CSP·1AA rates had significant linear effects on leaf P, the values being 0·074, 0·103, and 0·116 %P, respectively. It is interesting to note that these values are lower than the corresponding values for tops P for the same treatment (Table 38), which were 0·103, 0·135, and 0·199 %P. This indicates that, for these soils, and the treatment used, the % P in tops > % P in leaves, which implies that the harder or woody material of the tops had a higher %P than did the leaves. Leaf P for 1AA was 0·068% compared with 0·110% for CSP, a significant and expected difference. For the control, leaf P was 0·072 % compared with 0·093 % for the other treatment, also a significant difference (Table 38).

There is a close similarity between the effects of 1AA and CSP on root weight and the effects they had on tops yield. This is what would be expected especially because growth of the roots directly affects growth of the tops. The parts which were immediately in direct and continued contact with the treatments were the roots. Thus, as was the case with the tops weight, growth was significantly better for CSP (6·39 g) than for 1AA (3·37). As it was for tops weight, CSP rates had significant linear effect on root P. For soils effect, whereas Athi soil had higher tops P than Kabete soil for all CSP rates (Table 39), the reverse is true for root P as

Table 42. Interaction of soils on maize tops P for comparison of other treatment with the control.

Soils	Treatments: Others	Treatments: Control	Difference	Significant difference
	%			0.05 level
Athi	0.180	0.068	0.112	0.018
Kabete	0.128	0.105	0.023	

Table 43. Interaction of soils on maize leaf P for comparison of CSP forms.

Soils	CSP form: Powder	CSP form: Pellet	Difference	Significant difference
	%			0.05 level
Athi	0.117	0.107	0.010	0.018
Kabete	0.088	0.107	-0.019	

shown in Table 45. This showed that % P in roots for Kabete soil > for Athi soil, comparing the means for each rate. In other words, root yield and root P content for Kabete > root yield and root P for Athi. The CSP·1AA rates had effects very similar to CSP rates for root P for both soils, except that, at the highest rate, 112 kg/ha, root % P for CSP·1AA > root % P for CSP (Table 46 data compared with those in Table 45). As expected, root P was significantly more for CSP treatment than for 1AA as shown in Table 47 which also shows, as already pointed above, that root P for Kabete > root P for Athi for both CSP and 1AA treatments.

The forms of CSP in the soils significantly affected the amount of double acid-extractable P. For the powder form, the mean DA-P was 29·5 ppm compared with 41·3 ppm for the pellet form. The CSP rates (for both forms) had significant linear effects on DA-P which were 10·8, 29·3, and 48·5 ppm for the powder compared with 11·0, 30·2, and 83·0 ppm for the pellet. The greater effect of the pellet form and rates on DA-P compared with the powder is probably a reflection of more difficulty in sampling a soil which has been treated with pelletized P fertilizer such as was used and indeed there was much more variability between replicates of the soil treated with CSP pellets. This variability is due to the fact that dissolution of the pellet and its distribution in the soil is much slower compared with that of the powder. Thus any soil samples taken from a soil which had been treated with pelletized superphosphate fertilizer are likely to have residual pellets. For this reason, there is likely to be a greater variation among the

replicates with the highest rates of the fertilizer, as indicated by the values of 83·0 ppm of DA-P for the pellet compared with 48·5 ppm of DA-P for the powder form, corresponding to 112 kg P/ha rate as shown in Table 44. Such a sampling error is likely to be quite significant if sampling of soil is done within a few weeks or months following the fertilizer application and is likely to decrease after several years due to dissolution and distribution of the pellets.

CSP rates had a significant quadratic effect on DA-P (Table 48). There was no significant difference between the soils with regard to the highest CSP rate. The difference between the two soils in the DA-P for the lower rates is probably partly due to errors due to sampling (that is, if some samples contain pellets). There were significant form x rate effects on DA-P as already referred to in the discussion about the linear effects of CSP rates, as stated above. It is clear that responses to both sources are linear with different slopes. The CSP·1AA rates had significant linear effects on DA-P for both soils (Table 46).

Table 44. Means and responses of root weight and root P of <u>Zea mays</u> and of double acid-extractable soil P for two soils receiving three rates of 1AA and CSP sources.

Factor	Rate	Root weight	Root P	DA P	Comparisons No.	Type	Root weight	Root P	DA P
		g	%	ppm			Sum of squares		
<u>Treatment,</u>	<u>kg/ha</u>							**	**
Control		2.75	0.041	6.8					
1AA	r2	3.29	0.040	6.3	1	1AA,L			
1AA	r3	3.51	0.040	6.5	2	1AA,Q			
1AA	r4	3.32	0.043	6.8	3	CSP form			**
CSP powder	r5	6.04	0.057	10.8	4	CSP,L		*	**
CSP powder	r6	5.83	0.068	29.3	5	CSP,Q			
CSP powder	r7	5.94	0.089	48.5	6	Form x rate,L			**
CSP pellet	r5	5.25	0.057	11.0	7	Form x rate,Q			
CSP pellet	r6	6.10	0.071	30.2	8	CSP·1AA,L		**	**
CSP pellet	r7	5.87	01099	83.0	9	CSP·1AA,Q			
CSP·1AA	r2+r5	5.78	0.057	17.2	10	1AA vs CSP	*	**	**
CSP·1AA	r3+r6	6.27	0.069	26.5	11	CSP·1AA vs CSP+1AA			
CSP·1AA	r4+r7	6.42	0.111	49.4	12	Control vs others			
<u>Soils</u> (Treatments 5 to 10 only)									
Athi		5.37	0.067	36.8				*	
Kabete		6.30	0.079	34.1					
<u>Soils x treatments</u>						as above		**	
					1				
					2				
					3				
					4			**	
					5				**
					6				
					7				
					8			**	
					9				
					10			**	
					11				
					12				

* and ** denote significance at the 0.05 and 0.01 probability level, respectively, and letter L is for linear and Q for quadratic effects.

Table 45. Interaction of soils on maize root P for comparison of linear effect of CSP rates.

Soils	CSP rates, kg/ha 28	56	112	Significant difference
		Means		0.05 level
		Root P, %		0.012
Athi	0.046	0.062	0.095	
Kabete	0.068	0.077	0.093	

Table 46. Interaction of soils on maize root P and DA-P for comparison of linear effect of CSP·1AA rates.

Soils	CSP·1AA rates, kg/ha 28	56	112	Significant difference
		Means		0.05 level
		Root P, %		0.012
Athi	0.044	0.063	0.116	
Kabet	0.070	0.075	0.106	
		DA-P, ppm		11.2
Athi	18.9	30.3	46.5	
Kabete	15.5	22.8	52.2	

Table 47. Interaction of soils on maize root P for comparison of CSP with 1AA treatments.

Soils	Treatments CSP	1AA	Difference	Significant difference
	% P			0.05 level
Athi	0.068	0.026	0.042	0.012
Kabete	0.079	0.057	0.020	

Table 48. Interaction of two soils on DA-P extracted in the maize experiment for comparison of quadratic effect of CSP rates.

Soils	CSP rates, kg/ha 28	56	112	Significant difference
	PPM			0.05 level
Athi	8.0	37.1	65.3	11.2
Kabete	18.7	23.9	66.2	

REGRESSION RELATIONSHIPS

Correlation between the various yields and corresponding plant and soil P values are presented in Table 49 where N is the sample size upon which the estimate r was based. The level of significance is indicated by P.

Table 49. Correlation between yields and corresponding plant and soil P values.

Variables		N	r	p
Wt, Eucalyptus	P tops	234	0.286	<0.001
Wt, Eucalyptus	DA-P	234	0.115	0.078
Wt, Eucalyptus	SB-P	156	0.368	<0.001
Maize top Wt, (Residual P)	Maize top P	234	-0.106	0.105
Maize top Wt, (Residual P)	DA-P	234	-0.172	0.008
Maize top Wt, (Fresh P)	Maize top P	78	0.255	0.024
Maize top Wt, (Fresh P)	Leaf P	78	0.247	0.030
Maize top Wt, (Fresh P)	Root P	78	0.657	<0.001
Maize top Wt, (Fresh P)	DA-P	78	0.441	<0.001

The highest correlation obtained was between maize top weight (from soils with fresh P) and root P (with $p < 0.001$) in which $r = 0{\cdot}657$. There was also a high correlation ($r = 0{\cdot}441$) between maize top weight and DA-P. Weight yield of eucalyptus also had a high correlation with SB-P ($r = 0{\cdot}368$) with $p < 0{\cdot}001$.

The problem with the combined data presented in Table 49 is that there was a very large difference in P between Mwea soil on the one hand and Athi and Kabete soils on the other. Small variations in P from the means for Mwea soil, for example could

have been very large compared to those in the other soils. This is considered one of the reasons for poor correlations among the variables except a few of them compared to those below for each soil.

In view of this, it was thought appropriate to determine regression equations which could be used to predict such variables as tops P, leaf P, root P, and DA-P for each soil. The closer the r value is to ±1, the greater the correlation between the variables, and the better is the prediction for the dependent variable. In the following equations, tops P, leaf P, and root P are in %; DA=P and SB-P are in ppm. The symbols ** indicate significance at p = 0·01 and * indicates significance at p = 0·05, for 37 degrees of freedom (of the means of the variables considered). The equations have been partitioned under (i) Eucalypt Experiment, (ii) Maize Experiment with residual soil treatments, and (iii) Maize Experiment with new treatments.

(i) Eucalyptus Experiment

Athi Soil, 0- to 15-cm depth

Tops P = 0·082 + 0·00164(DA-P)
r = 0·843
t = 9·5**
Tops P = 0·074 + 0·0060(SB-P)
r = 0·794
t = 9·6**
DA-P = 3·86(SB-P) - 6·30
r = 0·982
t =31·6**

Athi soil, 15- to 30-cm depth

Tops P = 0·068 + 0·00134(DA-P)
r = 0·915
t =13·8**
Tops P = 0·061 + 0·00135(SB-P)
r = 0·743
t = 6·75**
DA-P = 8·11(SB-P) - 16
r = 0·985
t =35·15**

Mwea soil, 0- to 15-cm depth

Tops P = 0·0069(DA-P) - 0·243
r = 0·596
t = 4·52**
Tops P = 0·090 + 1·40(Leaf P)
r = 0·838
t =72·8**
Leaf P = 0·00033(DA-P) - 0·068
r = 0·475
t = 3·28**

Mwea soil, 15- to 30-cm depth

Tops P = 0·000868(DA-P) - 0·497
r = 0·74
t = 6·69**

Kabete, 0- to 15-cm depth

Tops P = 0·114 + 0·00193(DA-P)
r = 0·593
t = 4·47**
Tops P = 0·090 + 0·00278(SB-P)
r = 0·782
t = 7·59**
Tops P = 0·0168 + 0·970(Leaf P)
r = 0·857
t =10·1**
DA-P = 1·017(SB-P) - 0·35
r = 0·926
t =14·9**

Kabete soil, 15- to 30-cm depth

$$\text{Tops P} = 0{\cdot}083 + 0{\cdot}00408(\text{DA-P})$$
$$r = 0{\cdot}761$$
$$t = 6{\cdot}08^{**}$$
$$\text{Tops P} = 0{\cdot}071 + 0{\cdot}0043(\text{SB-P})$$
$$r = 0{\cdot}783$$
$$t = 7{\cdot}68^{**}$$
$$\text{DA-P} = 1{\cdot}02(\text{SB-P}) - 2{\cdot}43$$
$$r = 0{\cdot}994$$
$$t = 58{\cdot}0^{**}$$

(ii) Maize, Residual Soil Treatments

Athi soil, 0- to 15-cm depth

$$\text{Tops P} = 0{\cdot}089 + 0{\cdot}00104(\text{DA-P})$$
$$r = 0{\cdot}726$$
$$t = 6{\cdot}44^{**}$$

Athi soil, 15- to 30-cm depth

$$\text{Tops P} = 0{\cdot}084 + 0{\cdot}00113(\text{DA-P})$$
$$r = 0{\cdot}896$$
$$t = 12{\cdot}3^{**}$$

Mwea soil, 0- to 15-cm depth

$$\text{Tops P} = 0{\cdot}076 + 0{\cdot}00145(\text{DA-P})$$
$$r = 0{\cdot}371$$
$$t = 2{\cdot}42^{*}$$

Mwea soil, 15- to 30-cm depth

$$\text{Tops P} = 0{\cdot}00454(\text{DA-P}) - 0{\cdot}066$$
$$r = 0{\cdot}564$$
$$t = 5{\cdot}03^{**}$$

Kabete soil, 0- to 15-cm depth

$$\text{Tops P} = 0{\cdot}080 + 0{\cdot}000832(\text{DA-P})$$
$$r = 0{\cdot}645$$
$$t = 5{\cdot}13^{**}$$

Kabete soil, 15- to 30-cm depth

$$\text{Tops P} = 0{\cdot}0561 + 0{\cdot}00335(\text{DA-P})$$
$$r = 0{\cdot}319$$
$$t = 2{\cdot}16^{*}$$

(iii) Maize, New Treatments

Athi soil, 0- to 15-cm depth

Tops $P = 0{\cdot}092 + 0{\cdot}00244(\text{DA-P})$
$r = 0{\cdot}95$
$t = 18{\cdot}5^{**}$
Tops $P = 0{\cdot}005 + 1{\cdot}45(\text{Leaf P})$
$r = 0{\cdot}820$
$t = 8{\cdot}71^{**}$
Tops $P = 1{\cdot}645(\text{Root P}) - 0{\cdot}037$
$r = 0{\cdot}812$
$t = 8{\cdot}44^{**}$
Root $P = 0{\cdot}023 + 0{\cdot}00131(\text{DA-P})$
$r = 0{\cdot}945$
$t = 17{\cdot}7^{**}$
Leaf $P = 0{\cdot}0534 + 0{\cdot}772(\text{Root P})$
$r = 0{\cdot}574$
$t = 4{\cdot}26^{**}$

Kabete soil, 0- to 15-cm depth

Tops $P = 0{\cdot}11 + 0{\cdot}176(\text{DA-P})$
$r = 0{\cdot}283$
$t = 1{\cdot}79$
Tops $P = 0{\cdot}544 + 0{\cdot}844(\text{Root P})$
$r = 0{\cdot}238$
$t = 1{\cdot}46$
Leaf $P = 1{\cdot}22(\text{Root P}) - 0{\cdot}001$
$r = 0{\cdot}80$
$t = 8{\cdot}14^{**}$
Root $P = 0{\cdot}0117(\text{DA-P}) - 0{\cdot}179$
$r = 0{\cdot}765$
$t = 7{\cdot}21^{**}$
Leaf $P = 0{\cdot}071 + 0{\cdot}000675(\text{DA-P})$
$r = 0{\cdot}59$
$t = 4{\cdot}45^{**}$

There are highly significant correlations between the variables, except a few. Since there are high correlations between DA-P and SB-P for the soils in which both methods of soil P determinations were used, it would be preferable to use the DA method because it is quicker and more convenient. The main disadvantage with the SB method is that the soil extracts are usually dark colored (due to

organic matter extracted by the alkaline solution) so that they require organic matter removal with activated charcoal. This process is time-consuming.

The above equations give a clear indication that it is inappropriate to determine correlations of the variables for all the soils especially if they have large differences between P. It is much better to determine correlation for individual soils and depths. For soils in which both DA and SB were used as extractants, it is found that values obtained by either soil test give similar slopes of the equations for prediction because DA-P and SB-P are highly correlated.

In Kenya, the two methods which are most frequently used for soil P determination are DA and SB. This research should show how to improve the interpretation of soil test results by using the regression relationships. These can be used as the starting point.

CONCLUSIONS

(1) Both *Eucalyptus grandis* and *Zea mays* responded positively to rates of 28, 56, and 112 kg P/ha applied as CSP in either powder form or pellet form. Addition of IAA at preplant depressed *E. grandis* and stimulated *Z. mays* growth. Since the reaction and persistence of IAA in these or other soils are unknown, the level of IAA employed may not have matched the need these species had for endogenous IAA. Presence of IAA in CSP did not affect plant responses above or below that for corresponding rates of CSP.

(2) Phosphorus content of eucalypt and maize tops and leaves showed significant linear increases with respect to rates of applied CSP or CSP•IAA, showing that the fertilizer P was readily available to these species. The availability of P in the soil by DA-P or SB-P test was also highly correlated with the level of tops P so that soil test values appeared useful in predicting level of P in the plant.

(3) Regression relationships between soil test P and tops P or leaf P appeared that data for each soil, rather than grouping those of several soils, should be used in obtaining correlations between soil test and tissue data. Knowing this, it should prove valuable in conserving the use of phosphate on soils either natively high in P or attaining sufficient P from past fertilization. For both eucalypt and maize, leaf P was lower than tops P so that choice of foliar tissue should be considered in obtaining correlation data.

(4) From these studies, soils from either depth responded to CSP rather similarly so that recommendations on land subject to shallow erosion could be expected to respond to P alike those of the same soil with negligible erosion.

(5) Despite apparent P deficiency of plants grown on Athi and Kabete soils occurring shortly after emergence on control and 1AA treatments, E. grandis seedlings grew to the same height as those with CSP on Kabete soil whereas they did not on Athi soil. This was also true for dry weight of tops on Athi soil compared to Kabete and Mwea soils. Under the flooding conditions, increased P availability of native P in Kabete soil may have promoted more growth than that in Athi soil or Mwea soil. Lack of linear or quadratic responses in dry weight of eucalypt seedlings to rates of the CSP forms suggested that 28 kg P/ha was sufficient compared to that supplied by the soils for 1AA and control treatments.

(6) Maize weight responses to residual P from the eucalypt experiment did show a linear response to rates of the CSP forms in Athi and Kabete soils, particularly for CSP·1AA. Increased weight of maize tops at 28 kg P/ha over that without CSP was greatest for Kabete soil, which also gave the highest maize dry matter at the 56 and 112 kg P/ha levels compared to corresponding treatments in Athi and Mwea soils.

(7) Maize with preplant fertilization produced more dry weight on Kabete soil than Athi soil at each CSP rate of application. At 28 kg P/ha, dry matter was four times that without CSP in Athi soil and double that without CSP in Kabete soil.

APPENDIX

Table 50. Mean height and stem thickness of eucalyptus grown on o- to 15-cm depth of Athi soil treated with indole acetic acid (1AA) and three concentrated superphosphate (CSP) sources at three rates.

Rate		Height			Stem
		Months since emergence			
1AA	P	2	3	4	thickness
— kg/ha —			cm		mm
			Check		
0	0	6.2	16.2	41.0	3.9
			1AA		
0.031	0	7.0	18.2	49.1	4.0
0.062	0	5.9	16.3	48.6	4.0
0.124	0	4.1	13.9	39.8	3.5
			Powdered CSP		
0	28	14.6	28.4	47.8	5.4
0	56	26.2	37.3	57.7	5.3
0	112	20.4	30.8	51.4	5.3
			Pelletized CSP		
0	28	22.7	35.0	62.9	6.1
0	56	19.5	30.4	60.7	5.3
0	112	24.1	34.8	55.1	5.9
			Pelletized CSP with 1AA		
0.031	28	26.4	38.7	62.4	5.3
0.062	56	20.4	31.6	57.2	6.1
0.124	112	19.3	34.6	64.3	5.6

Table 51. Mean height and stem thickness of eucalyptus grown on 15- to 30-cm depth of Athi soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Height			Stem
		Months since emergence			
1AA	P	2	3	4	thickness
— kg/ha —		— cm —			mm
		Check			
0	0	4.8	10.2	32.7	3.1
		1AA			
0.031	0	4.1	9.2	37.2	2.7
0.062	0	2.2	4.1	15.5	1.8
0.124	0	2.9	7.2	24.1	2.3
		Powdered CSP			
0	28	12.4	26.7	59.1	5.3
0	56	18.7	33.6	66.7	5.2
0	112	20.8	33.7	56.8	5.1
		Pelletized CSP			
0	28	21.4	32.7	58.2	6.0
0	56	19.5	34.1	63.4	4.8
0	112	22.1	34.8	64.1	6.1
		Pelletized CSP with 1AA			
0.031	28	19.8	34.5	64.9	6.5
0.062	56	22.9	32.8	50.9	5.1
0.124	112	23.4	39.9	65.6	5.7

Table 52. Mean height and stem thickness of eucalyptus grown on 0- to 15-cm depth of Mwea soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Height			Stem
		Months since emergence			
1AA	P	2	3	4	thickness
kg/ha		cm			mm
		Check			
0	0	22.7	37.5	70.3	5.7
		1AA			
0.031	0	16.1	29.1	55.0	4.8
0.062	0	15.9	34.1	62.2	5.2
0.124	0	15.1	30.1	56.4	5.2
		Powdered CSP			
0	28	19.3	35.3	65.1	5.9
0	56	19.1	32.1	55.1	5.8
0	112	21.4	34.1	60.0	5.4
		Pelletized CSP			
0	28	18.2	31.1	58.4	5.8
0	56	20.5	35.5	67.6	5.7
0	112	17.1	31.8	58.1	5.4
		Pelletized CSP with 1AA			
0.031	28	23.1	35.5	62.2	5.8
0.062	56	21.0	35.2	61.0	5.7
0.124	112	20.6	32.7	60.1	5.2

Table 53. Mean height and stem thickness of eucalyptus grown on 15- to 30-cm depth of Mwea soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Height: Months since emergence			Stem thickness
1AA	P	2	3	4	
— kg/ha —		——— cm ———			mm
			Check		
0	0	15.2	26.7	49.0	5.3
			1AA		
0.031	0	8.0	18.3	51.9	4.1
0.062	0	11.2	23.8	50.9	5.3
0.124	0	10.5	25.0	55.3	4.9
			Powdered CSP		
0	28	21.6	35.7	56.8	5.5
0	56	22.3	40.1	71.6	5.8
0	112	18.9	31.2	57.6	5.7
			Pelletized CSP		
0	28	21.1	38.4	68.0	5.9
0	56	19.9	32.6	58.3	6.0
0	112	25.2	39.9	70.4	6.3
			Pelletized CSP with 1AA		
0.031	28	19.2	36.6	68.9	5.8
0.062	56	22.8	36.1	64.4	5.8
0.124	112	21.3	33.7	54.8	5.6

Table 54. Mean height and stem thickness of eucalyptus grown on 0- to 15-cm depth of Kabete soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Height			Stem
		Months since emergence			
1AA	P	2	3	4	thickness
—— kg/ha ——			cm		mm
			Check		
0	0	14.3	31.9	61.6	5.9
			1AA		
0.031	0	10.6	26.9	56.0	5.4
0.062	0	6.0	23.4	51.4	4.8
0.124	0	7.1	27.4	66.7	5.3
			Powdered CSP		
0	28	16.7	38.9	67.8	6.8
0	56	17.6	33.5	60.9	6.2
0	112	21.6	39.4	71.9	6.1
			Pelletized CSP		
0	28	11.2	25.1	50.0	5.7
0	56	9.3	28.6	66.6	5.8
0	112	12.1	28.9	65.7	5.1
			Pelletized CSP with 1AA		
0.031	28	6.4	22.9	58.1	5.1
0.062	56	7.6	24.7	59.2	5.5
0.124	112	9.4	25.8	56.1	5.8

Table 55. Mean height and stem thickness of eucalyptus grown on 15- to 30-cm depth of Kabete soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Height			Stem
		Months since emergence			
1AA	P	2	3	4	thickness
— kg/ha —			cm		mm
			Check		
0	0	10.9	30.3	55.8	5.9
			1AA		
0.031	0	4.1	22.3	69.9	4.8
0.062	0	5.2	24.6	69.4	4.9
0.124	0	5.9	23.7	60.9	5.0
			Powdered CSP		
0	28	12.4	27.7	52.3	5.4
0	56	16.4	33.4	61.8	5.7
0	112	15.8	31.6	62.0	5.1
			Pelletized CSP		
0	28	4.7	24.6	63.1	5.5
0	56	6.4	23.8	57.1	4.9
0	112	9.2	28.2	57.3	5.5
			Pelletized CSP with 1AA		
0.031	28	11.4	30.0	62.7	5.7
0.062	56	7.8	26.2	50.9	5.4
0.124	112	8.6	30.8	65.0	5.6

Table 56. Mean dry matter yield of eucalyptus tops from eucalyptus grown on three Kenya soils sampled at two depths and treated with indole acetic acid (1AA) and three concentrated superphosphate (CSP) sources at three rates.

Rate		Dry matter yield of eucalyptus tops					
		Athi (cm)		Mwea (cm)		Kabete (cm)	
1AA	P	0-15	15-30	0-15	15-30	0-15	15-30
— kg/ha —		g					
				Check			
0	0	8.85	5.37	22.56	20.63	24.45	23.57
				1AA			
0.031	0	8.60	4.41	17.63	13.16	21.39	17.13
0.062	0	8.59	2.74	16.96	15.87	17.49	18.76
0.124	0	6.15	3.00	19.56	18.32	19.93	18.57
				Powdered CSP			
0	28	22.81	18.96	22.48	21.85	33.77	23.00
0	56	22.81	22.37	22.18	25.42	25.64	25.58
0	112	22.73	20.31	24.71	22.82	31.10	19.90
				Pelletized CSP			
0	28	26.42	23.34	19.76	22.47	25.85	24.30
0	56	2188	16.26	23.47	25.12	22.16	23.71
0	112	28.55	26.34	20.95	25.92	22.23	26.30
				Pelletized CSP with 1AA			
0.031	28	23.64	24.38	23.46	26.30	17.81	21.33
0.062	56	23.43	20.41	21.57	23.64	16.02	25.37
0.124	112	20.93	22.81	18.53	23.20	25.22	23.63

Table 57. Mean analysis of eucalyptus tops sampled from 0- to 15-cm depth of Athi soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Eucalyptus top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
		Check							
0	0	0.053	1.25	0.20	0.90	11	50	413	66
		1AA							
0.031	0	0.066	1.31	0.22	1.06	12	53	450	36
0.062	0	0.057	1.29	0.24	0.96	12	80	457	45
0.124	0	0.066	1.02	0.20	0.91	13	60	440	46
		Powdered CSP							
0	28	0.101	1.10	0.18	0.76	8	47	623	39
0	56	0.139	0.94	0.15	0.69	8	40	553	36
0	112	0.217	1.15	0.17	0.75	8	40	660	41
		Pelletized CSP							
0	28	0.116	1.05	0.16	0.68	7	53	553	34
0	56	0.181	1.06	0.15	0.79	8	50	607	34
0	112	0.218	1.07	0.16	0.66	9	53	793	43
		Pelletized CSP with 1AA							
0.031	28	0.123	1.13	0.16	0.73	9	50	740	38
0.062	56	0.155	1.04	0.16	0.73	8	53	520	32
0.124	112	0.221	1.03	0.15	0.75	9	57	537	39

Table 58. Mean analysis of eucalyptus tops sampled from 15- to 30-cm depth of Athi soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Eucalyptus top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
				Check					
0	0	0.067	1.53	0.30	0.97	13	60	233	45
				1AA					
0.031	0	0.068	1.61	0.32	0.87	15	57	263	58
0.062	0	0.076	1.78	0.29	1.09	17	70	220	54
0.124	0	0.077	1.75	0.34	0.94	17	80	323	66
				Powdered CSP					
0	28	0.097	1.06	0.17	0.65	8	47	257	35
0	56	0.136	1.04	0.16	0.64	8	40	300	37
0	112	0.205	1.04	0.15	0.59	8	40	307	49
				Pelletized CSP					
0	28	0.093	0.95	0.15	0.62	8	107	323	40
0	56	0.187	1.53	0.22	0.63	9	63	413	56
0	112	0.211	1.00	0.15	0.60	8	77	330	39
				Pelletized CSP with 1AA					
0.031	28	0.095	0.92	0.14	0.54	7	37	300	36
0.062	56	0.152	1.12	0.17	0.53	7	43	300	46
0.124	112	0.198	1.12	0.17	0.58	9	43	370	50

Table 59. Mean analysis of eucalyptus tops sampled from 0- to 15-cm depth of Mwea soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Eucalyptus top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		—	%	—		—	ppm	—	
				Check					
0	0	0.089	0.91	0.18	0.69	8	43	220	35
				1AA					
0.031	0	0.096	1.08	0.21	0.70	8	40	237	36
0.062	0	0.083	1.03	0.21	0.67	7	43	233	38
0.124	0	0.083	0.83	0.18	0.67	7	45	240	30
				Powdered CSP					
0	28	0.091	0.92	0.18	0.60	6	37	227	27
0	56	0.139	0.96	0.19	0.60	6	47	250	34
0	112	0.158	1.06	0.20	0.60	6	63	313	41
				Pelletized CSP					
0	28	0.109	1.00	0.18	0.66	6	37	250	30
0	56	0.154	0.94	0.19	0.71	6	47	260	36
0	112	0.181	0.88	0.18	0.60	6	40	210	31
				Pelletized CSP with 1AA					
0.031	28	0.121	0.98	0.20	0.62	7	33	270	32
0.062	56	0.139	0.99	0.21	0.60	6	47	290	33
0.124	112	0.189	1.18	0.22	0.64	7	57	283	39

Table 60. Mean analysis of eucalyptus tops sampled from 15- to 30-cm depth of Mwea soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Eucalyptus top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
					Check				
0	0	0.064	1.03	0.24	0.56	8	50	183	39
					1AA				
0.031	0	0.080	1.04	0.25	0.67	7	40	133	33
0.062	0	0.080	1.15	0.26	0.61	7	37	250	35
0.124	0	0.074	1.09	0.24	0.60	7	40	227	34
					Powdered CSP				
0	28	0.083	1.13	0.23	0.49	6	37	193	37
0	56	0.115	1.18	0.24	0.52	6	37	177	43
0	112	0.146	1.09	0.21	0.53	6	33	207	40
					Pelletized CSP				
0	28	0.096	1.07	0.23	0.46	6	53	190	41
0	56	0.119	1.17	0.23	0.48	6	40	193	35
0	112	0.160	1.10	0.22	0.51	6	80	253	32
					Pelletized CSP with 1AA				
0.031	28	0.079	0.94	0.20	0.47	6	40	157	38
0.062	56	0.109	1.24	0.25	0.49	6	60	227	36
0.124	112	0.172	1.18	0.24	0.51	6	47	257	43

Table 61. Mean analysis of eucalyptus tops sampled from 0- to 15-cm depth of Kabete soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Eucalyptus top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
—— kg/ha ——		—— % ——				—— ppm ——			
					Check				
0	0	0.109	0.95	0.17	0.69	9	40	133	32
					1AA				
0.031	0	0.142	1.03	0.19	0.82	12	47	137	42
0.062	0	0.168	1.07	0.20	0.96	11	53	193	38
0.124	0	0.132	1.10	0.19	0.90	10	37	113	34
					Powdered CSP				
0	28	0.098	0.92	0.18	0.68	8	40	117	26
0	56	0.147	0.91	0.17	0.77	7	40	90	31
0	112	0.181	1.07	0.18	0.84	8	37	150	34
					Pelletized CSP				
0	28	0.147	0.96	0.17	0.81	8	53	117	33
0	56	0.171	0.95	0.17	0.88	8	40	93	34
0	112	0.187	0.82	0.14	0.81	8	73	90	30
					Pelletized CSP with 1AA				
0.031	28	0.155	0.94	0.17	0.92	10	47	130	30
0.062	56	0.160	0.84	0.15	0.85	8	40	103	26
0.124	112	0.192	1.08	0.19	0.94	9	43	127	33

Table 62. Mean analysis of eucalyptus tops sampled from 15- to 30-cm depth of Kabete soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Eucalyptus top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
—— kg/ha ——		——— % ———				——— ppm ———			
					Check				
0	0	0.051	1.11	0.18	0.77	7	40	230	38
					1AA				
0.031	0	0.076	1.20	0.19	0.84	9	40	213	43
0.062	0	0.057	1.29	0.22	0.99	10	43	250	48
0.124	0	0.057	1.21	0.22	0.96	11	40	243	41
					Powdered CSP				
0	28	0.117	1.18	0.19	0.69	8	47	237	42
0	56	0.141	1.09	0.17	0.67	9	43	217	40
0	112	0.212	1.33	0.18	0.79	8	37	210	38
					Pelletized CSP				
0	28	0.122	1.32	0.22	0.90	9	47	237	48
0	56	0.145	1.11	0.18	0.76	7	37	210	37
0	112	0.180	1.19	0.20	0.80	7	43	213	35
					Pelletized CSP with 1AA				
0.031	28	0.101	1.10	0.16	0.73	6	43	180	33
0.062	56	0.143	1.12	0.17	0.73	7	37	267	41
0.124	112	0.169	1.10	0.18	0.73	7	43	177	32

Table 63. Mean analysis of eucalyptus leaves sampled from eucalyptus trees grown on the 0- to 15-cm depth of Mwea soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Eucalyptus leaf composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
—— kg/ha ——		—— % ——				—— ppm ——			
					Check				
0	0	0.095	1.10	0.35	0.73	8	43	363	42
					1AA				
0.031	0	0.100	1.20	0.34	0.67	8	40	357	42
0.062	0	0.097	1.19	0.38	0.74	8	40	380	51
0.124	0	0.087	0.87	0.30	0.72	7	33	327	33
					Powdered CSP				
0	28	0.085	1.00	0.32	0.54	6	37	320	33
0	56	0.109	1.01	0.33	0.61	6	40	343	41
0	112	0.118	1.15	0.31	0.56	6	50	420	47
					Pelletized CSP				
0	28	0.110	1.12	0.34	0.65	6	37	370	35
0	56	0.110	1.04	0.31	0.69	7	40	360	42
0	112	0.137	1.21	0.36	0.72	7	60	390	37
					Pelletized CSP with 1AA				
0.031	28	0.101	0.97	0.32	0.64	6	37	383	37
0.062	56	0.112	0.98	0.32	0.62	6	33	413	35
0.124	112	0.148	1.21	0.37	0.66	7	40	447	44

Table 64. Mean analysis of eucalyptus leaves sampled from eucalyptus trees grown on the 0- to 15-cm depth of Kabete soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Eucalyptus leaf composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
				Check					
0	0	0.094	0.79	0.26	0.74	9	37	153	36
				1AA					
0.031	0	0.114	0.89	0.29	0.83	10	35	187	45
0.062	0	0.152	0.96	0.31	1.00	11	60	277	45
0.124	0	0.137	1.10	0.37	1.04	10	47	173	39
				Powdered CSP					
0	28	0.098	0.84	0.31	0.71	9	35	150	28
0	56	0.116	0.77	0.28	0.83	8	40	130	38
0	112	0.154	1.04	0.34	0.97	8	33	240	38
				Pelletized CSP					
0	28	0.113	0.77	0.25	0.83	7	37	143	31
0	56	0.148	0.92	0.30	0.97	9	43	144	38
0	112	0.182	0.92	0.30	1.10	8	33	150	39
				Pelletized CSP with 1AA					
0.031	28	0.129	0.84	0.32	0.97	9	40	167	35
0.062	56	0.134	0.87	0.33	0.97	9	40	173	33
0.124	112	0.152	1.09	0.34	1.03	9	60	187	36

Table 65. Mean analysis of 0- to 15-cm depth of Athi soil sampled after eucalyptus growth treated with indole acetic acid (1AA) and three concentrated superphosphate (CSP) sources at three rates.

Rate		P extracted		Extractable cations by DA method				
1AA	P	DA	SB	Ca	Mg	K	Cu	Zn
— kg/ha —		---- ppm ----		-------- %	------		-- ppm --	
				Check				
0	0	7.7	3.3	0.46	0.055	0.028	1.4	9.1
				1AA				
0.031	0	5.6	3.4	0.47	0.057	0.028	1.2	8.4
0.062	0	7.4	3.2	0.48	0.056	0.029	1.4	9.1
0.124	0	7.8	3.5	0.47	0.055	0.029	1.0	6.0
				Powdered CSP				
0	28	16.0	6.7	0.46	0.055	0.021	1.6	9.0
0	56	19.0	7.0	0.47	0.059	0.022	1.6	7.8
0	112	70.5	21.3	0.47	0.055	0.022	1.7	10.0
				Pelletized CSP				
0	28	9.5	4.4	0.46	0.057	0.023	1.2	7.9
0	56	27.2	8.4	0.48	0.056	0.023	1.1	6.7
0	112	85.7	22.9	0.49	0.059	0.021	1.1	6.0
				Pelletized CSP with 1AA				
0.031	28	14.9	5.3	0.47	0.059	0.022	1.7	10.3
0.062	56	45.0	12.7	0.47	0.055	0.023	1.0	5.7
0.124	112	77.5	22.3	0.49	0.058	0.024	1.0	6.8

Table66. Mean analysis of 15- to 30-cm depth of Athi soil sampled after eucalyptus growth treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		P extracted		Extractable cations by DA method				
1AA	P	DA	SB	Ca	Mg	K	Cu	Zn
— kg/ha —		— ppm —		— % —			— ppm —	
				Check				
0	0	10.9	2.7	0.53	0.054	0.019	0.8	3.9
				1AA				
0.031	0	16.3	3.1	0.54	0.058	0.019	0.8	4.8
0.062	0	8.8	3.1	0.55	0.061	0.020	0.8	5.4
0.124	0	12.2	2.5	0.55	0.059	0.019	0.9	3.9
				Powdered CSP				
0	28	23.6	3.7	0.53	0.055	0.016	1.1	6.4
0	56	52.5	6.8	0.53	0.055	0.013	1.2	4.8
0	112	96.2	15.2	0.55	0.056	0.013	1.4	5.9
				Pelletized CSP				
0	28	20.2	3.7	0.54	0.055	0.015	1.0	5.4
0	56	58.0	6.6	0.54	0.056	0.015	1.0	5.7
0	112	11.5	15.9	0.55	0.058	0.014	1.2	5.7
				Pelletized CSP with 1AA				
0.031	28	25.2	3.8	0.56	0.056	0.015	1.0	5.7
0.062	56	41.7	7.2	0.53	0.055	0.015	1.2	5.4
0.124	112	105.0	16.0	0.57	0.059	0.015	0.9	6.3

Table 67. Mean analysis of 0- to 15-cm depth of Mwea soil sampled after eucalyptus growth treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		P extracted	Extractable cations by DA method				
1AA	P	DA	Ca	Mg	K	Cu	Zn
kg/ha		ppm	%			ppm	
			Check				
0	0	512	0.72	0.121	0.013	1.0	6.9
			1AA				
0.031	0	500	0.69	0.122	0.015	1.0	6.1
0.062	0	493	0.68	0.118	0.017	0.9	6.3
0.124	0	497	0.69	0.122	0.013	0.9	6.1
			Powdered CSP				
0	28	513	0.70	0.120	0.014	0.9	5.5
0	56	528	0.70	0.123	0.014	1.0	6.6
0	112	567	0.68	0.120	0.013	0.9	6.3
			Pelletized CSP				
0	28	548	0.71	0.125	0.015	0.9	6.7
0	56	572	0.73	0.129	0.012	1.1	7.5
0	112	595	0.72	0.126	0.014	0.8	4.6
			Pelletized CSP with 1AA				
0.031	28	498	0.69	0.122	0.014	1.1	7.6
0.062	56	543	0.70	0.125	0.014	0.8	4.4
0.124	112	560	0.69	0.119	0.014	0.8	3.5

Table 68. Mean analysis of 15- to 30-cm depth of Mwea soil sampled after eucalyptus growth treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		P extracted	Extractable cations by DA method				
1AA	P	DA	Ca	Mg	K	Cu	Zn
— kg/ha —		ppm	— % —			— ppm —	
			Check				
0	0	550	0.75	0.143	0.007	0.8	7.3
			1AA				
0.031	0	537	0.76	0.144	0.009	0.8	5.7
0.062	0	538	0.73	0.136	0.009	1.0	9.1
0.124	0	542	0.74	0.140	0.007	0.8	7.3
			Powdered CSP				
0	28	583	0.74	0.141	0.008	1.0	10.2
0	56	600	0.74	0.136	0.006	0.7	6.2
0	112	617	0.73	0.136	0.008	0.9	10.3
			Pelletized CSP				
0	28	582	0.76	0.139	0.009	0.8	8.6
0	56	603	0.73	0.136	0.007	0.8	7.8
0	112	593	0.73	0.133	0.006	0.7	4.0
			Pelletized CSP with 1AA				
0.031	28	562	0.73	0.141	0.008	0.7	5.4
0.062	56	560	0.73	0.139	0.007	0.7	4.8
0.124	112	607	0.73	0.141	0.007	0.8	5.3

Table 69. Mean analysis of 0- to 15-cm depth of Kabete soil sampled after eucalyptus growth treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		P extracted		Extractable cations by DA method				
1AA	P	DA	SB	Ca	Mg	K	Cu	Zn
— kg/ha —		— ppm —		— % —			— ppm —	
				Check				
0	0	8.2	13.0	0.55	0.065	0.055	0.7	64
				1AA				
0.031	0	11.0	15.1	0.59	0.067	0.068	0.7	64
0.062	0	9.5	14.2	0.55	0.061	0.072	0.8	54
0.124	0	11.0	15.5	0.60	0.072	0.067	0.7	59
				Powdered CSP				
0	28	15.6	19.8	0.59	0.064	0.055	0.7	53
0	56	19.3	22.6	0.56	0.065	0.060	0.7	59
0	112	35.7	35.1	0.56	0.062	0.056	0.8	58
				Pelletized CSP				
0	28	15.4	18.9	0.56	0.065	0.062	0.7	55
0	56	24.5	29.3	0.60	0.070	0.063	0.8	77
0	112	40.8	34.8	0.60	0.068	0.061	0.7	62
				Pelletized CSP with 1AA				
0.031	28	15.2	19.1	0.59	0.067	0.066	0.7	55
0.062	56	22.1	31.1	0.56	0.070	0.070	0.7	56
0.124	112	32.0	35.1	0.56	0.067	0.061	0.6	57

Table 70. Mean analysis of 15- to 30-cm depth of Kabete soil sampled after eucalyptus growth treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		P extracted		Extractable cations by DA method				
1AA	P	DA	SB	Ca	Mg	K	Cu	Zn
— kg/ha —		— ppm —		— % —			— ppm —	
				Check				
0	0	1.6	3.3	0.39	0.046	0.051	0.8	37
				1AA				
0.031	0	1.8	3.6	0.37	0.043	0.048	0.7	34
0.062	0	2.0	3.6	0.38	0.044	0.052	0.8	32
0.124	0	2.0	3.5	0.39	0.043	0.050	0.7	29
				Powdered CSP				
0	28	5.3	8.6	0.37	0.043	0.045	0.7	32
0	56	8.0	10.7	0.37	0.042	0.045	0.7	34
0	112	26.3	26.3	0.38	0.043	0.043	0.6	35
				Pelletized CSP				
0	28	3.7	6.5	0.38	0.042	0.046	0.6	32
0	56	9.4	12.3	0.37	0.042	0.045	0.8	33
0	112	28.9	30.2	0.39	0.044	0.046	0.7	40
				Pelletized CSP with 1AA				
0.031	28	5.9	8.9	0.39	0.045	0.048	0.7	32
0.062	56	7.9	10.4	0.38	0.041	0.044	0.7	34
0.124	112	18.9	22.3	0.38	0.043	0.048	0.7	32

Table 71. Mean analysis of 0- to 15-cm depth of Mwea soil sampled after eucalyptus growth treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Extractable cations by N NH_4Cl method			
1AA	P	Ca	Mg	K	Na
— kg/ha —		— % —			
		Check			
0	0	0.78	0.15	0.020	0.012
		1AA			
0.031	0	0.79	0.16	0.021	0.010
0.062	0	0.87	0.17	0.023	0.010
0.124	0	0.94	0.17	0.020	0.011
		Powdered CSP			
0	28	0.91	0.16	0.020	0.011
0	56	0.89	0.16	0.020	0.010
0	112	0.95	0.18	0.019	0.010
		Pelletized CSP			
0	28	0.95	0.18	0.021	0.010
0	56	0.96	0.18	0.018	0.010
0	112	0.95	0.17	0.019	0.010
		Pelletized CSP with 1AA			
0.031	28	0.90	0.16	0.020	0.010
0.062	56	0.95	0.17	0.020	0.011
0.124	112	0.94	0.16	0.020	0.010

Table 72. Mean analysis of 15- to 30-cm depth of Mwea soil sampled after eucalyptus growth treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Extractable cations by N NH_4Cl method			
1AA	P	Ca	Mg	K	Na
—— kg/ha ——		—————— % ——————			
		Check			
0	0	0.95	0.19	0.012	.006
		1AA			
0.031	0	0.97	0.19	0.015	.006
0.062	0	0.95	0.20	0.015	.005
0.124	0	0.97	0.20	0.012	.006
		Powdered CSP			
0	28	0.92	0.19	0.012	.005
0	56	0.97	0.19	0.011	.005
0	112	0.99	0.19	0.014	.007
		Pelletized CSP			
0	28	0.96	0.20	0.013	.005
0	56	0.97	0.20	0.012	.005
0	112	0.97	0.21	0.011	.006
		Pelletized CSP with 1AA			
0.031	28	0.94	0.20	0.012	.006
0.062	56	0.99	0.20	0.012	.005
0.124	112	0.94	0.20	0.012	.005

Table 73. Mean height of maize grown on 0- to 15-cm depth of undisturbed Athi soil with treatments previously used for eucalyptus.

Rate		Height		
		Weeks since emergence		
1AA	P	2	4	6
— kg/ha —		— cm —		
		Check		
0	0	37.7	59.3	79.0
		1AA		
0.031	0	45.5	73.9	88.5
0.062	0	36.8	65.3	89.0
0.124	0	42.0	67.0	86.9
		Powdered CSP		
0	28	31.0	70.8	100.8
0	56	42.0	77.9	108.5
0	112	36.1	71.9	104.1
		Pelletized CSP		
0	28	34.5	69.7	102.5
0	56	37.8	72.1	106.5
0	112	33.3	72.6	109.8
		Pelletized CSP with 1AA		
0.031	28	33.9	70.6	104.7
0.062	56	33.0	71.9	105.3
0.124	112	30.9	68.7	103.6

Table 74. Mean height of maize grown on 15- to 30-cm depth of undisturbed Athi soil with treatments previously used for eucalyptus.

Rate		Height		
		Weeks since emergence		
1AA	P	2	4	6
— kg/ha —		cm		
		Check		
0	0	35.2	63.3	84.6
		1AA		
0.031	0	40.4	61.1	78.2
0.062	0	43.9	64.1	81.8
0.124	0	35.2	59.2	76.6
		Powdered CSP		
0	28	32.9	64.9	90.6
0	56	31.2	63.9	95.5
0	112	28.2	58.7	93.0
		Pelletized CSP		
0	28	33.8	66.1	92.7
0	56	30.5	67.0	100.1
0	112	33.4	65.0	99.1
		Pelletized CSP with 1AA		
0.031	28	29.4	59.0	85.8
0.062	56	36.2	71.0	96.8
0.124	112	31.6	69.8	104.0

Table 75. Mean height of maize grown on 0- to 15-cm depth of undisturbed Mwea soil with treatments previously used for eucalyptus.

Rate		Height		
		Weeks since emergence		
1AA	P	2	4	6
— kg/ha —		cm		
		Check		
0	0	39.2	74.4	108.0
		1AA		
0.031	0	34.1	68.3	98.3
0.062	0	40.4	70.9	99.9
0.124	0	40.7	74.9	102.7
		Powdered CSP		
0	28	43.0	73.8	107.0
0	56	36.3	70.0	104.6
0	112	37.6	69.4	102.0
		Pelletized CSP		
0	28	41.3	71.4	102.3
0	56	31.3	69.2	107.5
0	112	37.6	71.8	105.1
		Pelletized CSP with 1AA		
0.031	28	33.8	71.2	104.2
0.062	56	32.6	67.9	108.9
0.124	112	32.8	69.3	104.9

Table 76. Mean height of maize grown on 15- to 30-cm depth of undisturbed Mwea soil with treatments previously used for eucalyptus.

Rate		Height		
		Weeks since emergence		
1AA	P	2	4	6
— kg/ha —		——— cm ———		
		Check		
0	0	32.2	62.4	89.7
		1AA		
0.031	0	36.0	66.0	92.9
0.062	0	34.9	65.2	90.8
0.124	0	36.8	66.1	94.8
		Powdered CSP		
0	28	32.1	66.1	98.7
0	56	33.4	64.0	97.4
0	112	33.5	66.7	99.8
		Pelletized CSP		
0	28	33.0	61.1	92.0
0	56	33.0	65.1	99.4
0	112	30.1	66.9	101.5
		Pelletized CSP with 1AA		
0.031	28	30.7	63.1	95.8
0.062	56	36.5	69.7	95.8
0.124	112	27.1	64.8	101.2

Table 77. Mean height of maize grown on 0- to 15-cm depth of undisturbed Kabete soil with treatments previously used for eucalyptus.

Rate		Height		
		Weeks since emergence		
1AA	P	2	4	6
—— kg/ha ——		—— cm ——		
		Check		
0	0	47.2	88.1	116.4
		1AA		
0.031	0	45.1	83.1	111.5
0.062	0	48.4	86.6	112.2
0.124	0	47.2	85.7	114.2
		Powdered CSP		
0	28	49.0	91.1	119.2
0	56	50.0	99.2	124.3
0	112	51.3	100.9	125.9
		Pelletized CSP		
0	28	48.4	94.9	120.3
0	56	49.7	95.7	119.8
0	112	50.4	101.7	125.4
		Pelletized CSP with 1AA		
0.031	28	48.7	92.9	124.2
0.062	56	50.9	90.0	115.3
0.124	112	55.2	101.8	126.4

Table 78. Mean height of maize grown on 15- to 30-cm depth of undisturbed Kabete soil with treatments previously used for eucalyptus.

Rate		Height		
		Weeks since emergence		
1AA	P	2	4	6
— kg/ha —		— cm —		
		Check		
0	0	47.0	67.1	78.4
		1AA		
0.031	0	45.1	64.2	72.7
0.062	0	43.5	60.6	70.1
0.124	0	44.2	62.5	72.8
		Powdered CSP		
0	28	46.5	69.6	84.7
0	56	45.3	76.7	94.6
0	112	47.9	79.6	102.7
		Pelletized CSP		
0	28	43.9	72.6	91.9
0	56	47.8	75.8	98.4
0	112	47.4	82.1	106.0
		Pelletized CSP with 1AA		
0.031	28	43.9	68.9	89.0
0.062	56	47.7	78.7	100.0
0.124	112	50.8	86.1	113.3

Table 79. Mean dry matter yield of maize tops grown on Kenya soils undisturbed after treatments previously used for eucalyptus.

Rate		Dry matter yield of maize tops					
		Athi (cm)		Mwea (cm)		Kabete (cm)	
1AA	P	0-15	15-30	0-15	15-30	0-15	15-30
— kg/ha —		g					
				Check			
0	0	6.59	6.07	12.31	8.53	19.74	5.13
				1AA			
0.031	0	8.29	5.19	11.66	9.63	22.14	5.10
0.062	0	6.84	6.47	12.92	9.40	18.69	4.51
0.124	0	7.30	4.95	12.41	10.65	21.84	4.71
				Powdered CSP			
0	28	9.09	8.83	15.54	9.39	22.20	7.16
0	56	13.92	9.26	13.72	9.73	28.93	10.77
0	112	15.47	9.97	14.14	11.01	32.48	15.98
				Pelletized CSP			
0	28	11.64	8.21	13.25	9.55	27.98	9.22
0	56	13.60	9.08	11.58	9.42	29.55	13.41
0	112	12.52	12.66	14.34	11.35	40.10	19.57
				Pelletized CSP with 1AA			
0.031	28	9.85	7.67	12.87	9.00	27.19	8.69
0.062	56	12.60	12.37	13.50	8.75	26.69	13.34
0.124	112	12.36	11.72	13.63	10.38	36.04	20.87

Table 80. Mean analysis of maize tops sampled from 0- to 15-cm depth of undisturbed Athi soil with treatments previously used for eucalyptus.

Rate 1AA	Rate P	Maize top composition P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		——— % ———				——— ppm ———			
				Check					
0	0	0.076	0.43	0.18	3.80	7	73	61	30
				1AA					
0.031	0	0.068	0.45	0.20	3.67	6	53	56	27
0.062	0	0.079	0.39	0.19	4.33	6	45	58	29
0.124	0	0.072	0.42	0.19	4.33	7	87	58	31
				Powdered CSP					
0	28	0.101	0.37	0.16	4.03	7	65	61	29
0	56	0.113	0.41	0.16	2.73	5	53	59	26
0	112	0.138	0.49	0.16	2.43	6	40	64	20
				Pelletized CSP					
0	28	0.098	0.56	0.14	3.10	6	53	52	21
0	56	0.117	0.54	0.16	2.80	6	57	57	19
0	112	0.165	0.56	0.15	2.70	6	50	59	20
				Pelletized CSP with 1AA					
0.031	28	0.102	0.55	0.15	4.10	7	70	52	24
0.062	56	0.131	0.55	0.16	3.40	6	73	58	23
0.124	112	0.170	0.51	0.14	3.53	6	60	56	21

Table 81. Mean analysis of maize tops sampled from 15- to 30-cm depth of undisturbed Athi soil with treatments previously used for eucalyptus.

Rate		Maize top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
		Check							
0	0	0.081	0.56	0.22	3.10	7	63	28	36
		1AA							
0.031	0	0.077	0.49	0.26	2.53	8	50	35	46
0.062	0	0.076	0.57	0.27	2.09	8	97	36	46
0.124	0	0.079	0.61	0.24	2.57	8	80	33	41
		Powdered CSP							
0	28	0.099	0.51	0.24	1.55	8	53	38	34
0	56	0.128	0.49	0.26	0.62	7	70	38	29
0	112	0.158	0.56	0.24	0.91	6	47	40	28
		Pelletized CSP							
0	28	0.101	0.51	0.24	1.47	7	53	37	33
0	56	0.126	0.53	0.19	1.32	6	73	33	26
0	112	0.177	0.49	0.24	0.69	4	45	44	25
		Pelletized CSP with 1AA							
0.031	28	0.104	0.47	0.23	1.44	7	67	38	33
0.062	56	0.111	0.45	0.22	0.75	6	73	38	25
0.124	112	0.177	0.48	0.18	0.85	5	47	34	23

Table 82. Mean analysis of maize tops sampled from 0- to 15-cm depth of undisturbed Mwea soil with treatments previously used for eucalyptus.

Rate		Maize top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
		Check							
0	0	0.129	0.48	0.34	1.40	6	60	46	29
		1AA							
0.031	0	0.128	0.41	0.34	1.41	7	113	46	28
0.062	0	0.128	0.41	0.32	0.47	6	90	46	26
0.124	0	0.136	0.47	0.35	1.39	6	45	49	27
		Powdered CSP							
0	28	0.132	0.40	0.30	1.22	6	60	49	21
0	56	0.155	0.56	0.31	1.23	6	53	44	25
0	112	0.177	0.77	0.32	1.16	5	43	54	23
		Pelletized CSP							
0	28	0.138	0.75	0.32	1.30	5	80	43	23
0	56	0.176	0.60	0.36	1.31	7	53	47	34
0	112	0.167	0.66	0.28	0.86	4	80	42	20
		Pelletized CSP with 1AA							
0.031	28	0.139	0.68	0.31	1.23	6	60	46	22
0.062	56	0.151	0.57	0.31	1.26	5	63	49	24
0.124	112	0.181	0.44	0.28	1.20	5	67	49	22

Table 83. Mean analysis of maize tops sampled from 15- to 30-cm depth of undisturbed Mwea soil with treatments previously used for eucalyptus.

Rate		Maize top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
					Check				
0	0	0.143	.42	0.50	0.74	5	65	39	27
					1AA				
0.031	0	0.140	0.45	0.45	0.70	5	57	40	27
0.062	0	0.145	0.41	0.47	0.71	5	70	43	32
0.124	0	0.138	0.44	0.47	0.57	5	60	46	25
					Powdered CSP				
0	28	0.161	0.53	0.50	0.70	6	55	44	29
0	56	0.165	0.45	0.54	0.60	5	57	44	27
0	112	0.193	0.46	0.47	0.67	5	47	40	25
					Pelletized CSP				
0	28	0.153	0.55	0.50	0.82	5	67	39	32
0	56	0.202	0.71	0.54	0.48	5	50	46	26
0	112	0.205	0.65	0.45	0.66	5	55	52	24
					Pelletized CSP with 1AA				
0.031	28	0.174	0.63	0.51	0.88	5	67	43	33
0.062	56	0.200	0.61	0.57	0.65	6	80	47	30
0.124	112	0.220	0.43	0.50	0.81	5	60	42	27

Table 84. Mean analysis of maize tops sampled from 0- to 15-cm depth of undisturbed Kabete soil with treatments previously used for eucalyptus.

Rate		Maize top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		%				ppm			
					Check				
0	0	0.076	0.45	0.20	3.09	6	73	35	23
					1AA				
0.031	0	0.091	0.50	0.23	3.77	7	50	55	40
0.062	0	0.083	0.44	0.19	4.23	7	50	55	34
0.124	0	0.080	0.37	0.18	3.70	6	37	34	33
					Powdered CSP				
0	28	0.082	0.45	0.19	2.81	6	53	54	28
0	56	0.091	0.44	0.20	1.67	5	37	42	28
0	112	0.101	0.40	0.19	1.65	5	30	40	24
					Pelletized CSP				
0	28	0.090	0.43	0.18	2.79	5	57	48	26
0	56	0.098	0.57	0.15	2.10	5	33	36	23
0	112	0.097	0.47	0.16	1.09	5	67	59	21
					Pelletized CSP with 1AA				
0.031	28	0.093	0.58	0.18	2.33	8	40	65	30
0.062	56	0.096	0.45	0.16	2.54	5	47	40	25
0.124	112	0.106	0.46	0.17	1.43	5	40	32	22

Table 85. Mean analysis of maize tops sampled from 15- to 30-cm depth of undisturbed Kabete soil with treatments previously used for eucalyptus.

Rate		Maize top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
				Check					
0	0	0.063	0.46	0.27	6.07	7	53	48	39
				1AA					
0.031	0	0.066	0.62	0.27	6.10	7	70	72	39
0.062	0	0.061	0.74	0.25	5.00	7	50	56	39
0.124	0	0.064	0.98	0.27	5.27	7	57	81	50
				Powdered CSP					
0	28	0.065	0.64	0.19	4.80	7	73	46	32
0	56	0.073	0.64	0.19	5.13	6	47	43	27
0	112	0.094	0.51	0.17	3.63	4	50	44	25
				Pelletized CSP					
0	28	0.075	0.60	0.22	4.93	5	55	56	29
0	56	0.081	0.57	0.19	3.57	5	50	62	25
0	112	0.104	0.48	0.19	3.05	4	43	45	23
				Pelletized CSP with 1AA					
0.031	28	0.071	0.71	0.24	5.10	6	45	55	30
0.062	56	0.081	0.56	0.20	4.20	5	60	56	27
0.124	112	0.109	0.49	0.15	3.80	5	40	41	22

Table 86--Means and treatment comparisons for various elements in tops of *Zea mays* grown on three soils having residual 1AA and CSP treatments.

Factor	Ca	Mg	K	Cu	Fe	Mn	Zn
	Sum of squares for comparisons						
Treatment, kg/ha	**	**	**	**	**		**
1 1AA,L	*						
2 1AA,Q							
3 CSP form	**			**			
4 CSP,L		*	**	**	*		**
5 CSP,Q							
6 Form x rate,L							
7 Form x rate,Q							
8 CSP·1AA,L	**	**	**	**		*	**
9 CSP·1AA,Q							
10 1AA vs CSP		**	**	**	**		**
11 CSP·1AA vs CSP+1AA		*					**
12 Control vs others	**	*		*		*	*
Soils	**	**	**	**	**	**	**
Soils x treatments	**	**	**		**	*	**
1					**		
2							
3	**						
4	**		**				
5		*			*		
6							
7							
8	**					**	
9							
10	**	**	**			**	**
11							
12							
Soil depths	**	**				**	**
Depths x treatment	*						
1	**						
2			*				
3							
4	*						
5							*
6	*						
7				*			
8							
9							
10	**						*
11	*						
12			**				
Soils x depths	**	**		*		**	**

* and ** denote significance at the 0.05 and 0.01 level, respectively, and the letters L and Q stand for linear and quadratic, respectively.

Table 87. Mean analysis of 0- to 15-cm depth of Athi soil sampled after maize growth on undisturbed soil containing prior treatments for eucalyptus.

Rate 1AA	Rate P	P extracted DA	Extractable cations by DA method Ca	Mg	K	Cu	Zn
— kg/ha —		ppm	%			ppm	
			Check				
0	0	4.4	0.53	0.055	0.020	1.0	0.6
			1AA				
0.031	0	3.5	0.50	0.055	0.018	1.0	0.6
0.062	0	3.5	0.61	0.070	0.024	1.3	1.1
0.124	0	2.9	0.50	0.056	0.018	1.3	1.2
			Powdered CSP				
0	28	5.0	0.50	0.055	0.016	1.2	1.1
0	56	15.8	0.50	0.056	0.015	0.9	0.7
0	112	43.5	0.51	0.055	0.014	1.0	0.8
			Pelletized CSP				
0	28	6.0	0.51	0.056	0.015	1.1	1.0
0	56	21.0	0.51	0.056	0.015	1.4	1.0
0	112	65.7	0.50	0.056	0.014	1.1	0.9
			Pelletized CSP with 1AA				
0.031	28	8.7	0.51	0.055	0.016	1.5	1.1
0.062	56	12.9	0.51	0.054	0.015	1.5	1.0
0.124	112	64.8	0.51	0.055	0.015	1.4	1.0

Table 88. Mean analysis of 15- to 30-cm depth of Athi soil sampled after maize growth on undisturbed soil containing prior treatments for eucalyptus.

Rate		P extracted	Extractable cations by DA method				
1AA	P	DA	Ca	Mg	K	Cu	Zn
— kg/ha —		ppm	—	% —		— ppm —	
			Check				
0	0	9.0	0.60	0.058	0.013	0.8	0.8
			1AA				
0.031	0	7.8	0.61	0.061	0.015	0.8	0.6
0.062	0	5.6	0.60	0.059	0.014	0.9	0.7
0.124	0	6.2	0.62	0.060	0.015	0.7	0.5
			Powdered CSP				
0	28	11.4	0.60	0.060	0.012	0.9	1.1
0	56	15.8	0.60	0.057	0.012	0.8	0.8
0	112	85.2	0.60	0.058	0.013	0.7	0.7
			Pelletized CSP				
0	28	24.5	0.60	0.060	0.012	0.8	0.8
0	56	23.2	0.59	0.058	0.011	0.8	0.8
0	112	64.5	0.60	0.059	0.012	0.7	0.8
			Pelletized CSP with 1AA				
0.031	28	18.5	0.61	0.059	0.012	0.8	0.9
0.062	56	27.9	0.60	0.058	0.012	0.7	0.7
0.124	112	53.9	0.61	0.060	0.012	0.8	1.0

Table 89. Mean analysis of 0- to 15-cm depth of Mwea soil sampled after maize growth on undisturbed soil containing prior treatments for eucalyptus.

Rate		P extracted	Extractable cations by DA method				
1AA	P	DA	Ca	Mg	K	Cu	Zn
— kg/ha —		ppm	— % —			— ppm —	
			Check				
0	0	440	0.78	0.129	0.008	1.0	1.1
			1AA				
0.031	0	473	0.78	0.124	0.008	0.8	0.8
0.062	0	464	0.80	0.120	0.008	0.8	0.8
0.124	0	453	0.78	0.125	0.008	0.9	0.9
			Powdered CSP				
0	28	465	0.78	0.118	0.008	1.0	1.2
0	56	494	0.78	0.122	0.008	0.7	1.0
0	112	488	0.77	0.122	0.008	1.2	1.2
			Pelletized CSP				
0	28	469	0.81	0.124	0.008	0.9	0.9
0	56	577	0.80	0.122	0.008	1.0	0.9
0	112	558	0.79	0.121	0.008	1.1	1.2
			Pelletized CSP with 1AA				
0.031	28	512	0.77	0.118	0.007	0.9	0.8
0.062	56	593	0.81	0.123	0.008	0.9	0.9
0.124	112	520	0.77	0.119	0.009	1.3	1.1

Table 90. Mean analysis of 15- to 30-cm depth of Mwea soil sampled after maize growth on undisturbed soil containing prior treatments for eucalyptus.

Rate		P extracted	Extractable cations by DA method				
1AA	P	DA	Ca	Mg	K	Cu	Zn
— kg/ha —		ppm	%			— ppm —	
			Check				
0	0	489	0.85	0.148	0.006	0.9	1.2
			1AA				
0.031	0	467	0.86	0.148	0.005	0.8	0.9
0.062	0	490	0.85	0.146	0.006	0.8	0.9
0.124	0	451	0.82	0.145	0.005	0.8	0.9
			Powdered CSP				
0	28	531	0.83	0.144	0.005	1.0	1.0
0	56	552	0.92	0.143	0.005	0.9	1.0
0	112	578	0.91	0.141	0.005	1.0	1.2
			Pelletized CSP				
0	28	531	0.84	0.144	0.005	0.8	1.0
0	56	544	0.85	0.144	0.005	0.8	0.8
0	112	549	0.82	0.146	0.005	0.8	0.9
			Pelletized CSP with 1AA				
0.031	28	536	0.86	0.145	0.005	0.9	0.9
0.062	56	543	0.91	0.143	0.005	0.9	1.0
0.124	112	591	0.92	0.145	0.005	0.9	0.8

Table 91. Mean analysis of 0- to 15-cm depth of Kabete soil sampled after maize growth on undisturbed soil containing prior treatments for eucalyptus.

Rate		P extracted	Extractable cations by DA method				
1AA	P	DA	Ca	Mg	K	Cu	Zn
— kg/ha —		ppm	——— % ———			—— ppm ——	
			Check				
0	0	7.1	0.65	0.063	0.020	0.9	5.8
			1AA				
0.031	0	7.1	0.64	0.058	0.015	1.0	7.0
0.062	0	6.9	0.63	0.063	0.024	0.9	5.6
0.124	0	6.8	0.65	0.062	0.018	0.8	6.1
			Powdered CSP				
0	28	9.2	0.62	0.062	0.013	0.9	5.5
0	56	13.6	0.64	0.061	0.012	0.8	5.6
0	112	22.9	0.61	0.057	0.012	1.1	6.0
			Pelletized CSP				
0	28	8.3	0.62	0.059	0.015	0.9	5.8
0	56	14.6	0.65	0.062	0.013	0.9	6.0
0	112	27.3	0.63	0.058	0.009	0.8	6.4
			Pelletized CSP with 1AA				
0.031	28	11.8	0.65	0.063	0.015	0.8	5.9
0.062	56	13.0	0.64	0.063	0.016	0.9	7.1
0.124	112	30.0	0.66	0.062	0.013	0.9	6.1

Table 92. Mean analysis of 15- to 30-cm depth of Kabete soil sampled after maize growth on undisturbed soil containing prior treatments for eucalyptus.

Rate		P extracted	Extractable cations by DA method				
1AA	P	DA	Ca	Mg	K	Cu	Zn
— kg/ha —		ppm	—	%	—	— ppm —	
			Check				
0	0	1.8	0.40	0.044	0.033	1.0	4.4
			1AA				
0.031	0	1.9	0.40	0.042	0.030	1.0	4.6
0.062	0	1.7	0.41	0.044	0.035	1.0	5.2
0.124	0	1.4	0.40	0.043	0.035	0.9	4.3
			Powdered CSP				
0	28	3.0	0.39	0.044	0.021	1.2	4.9
0	56	7.1	0.41	0.044	0.015	1.2	4.6
0	112	12.6	0.39	0.043	0.011	1.2	4.9
			Pelletized CSP				
0	28	5.0	0.39	0.042	0.018	1.0	5.1
0	56	11.0	0.40	0.042	0.013	1.1	5.2
0	112	16.6	0.41	0.044	0.013	1.1	5.1
			Pelletized CSP with 1AA				
0.031	28	3.2	0.40	0.044	0.021	1.0	4.4
0.062	56	4.8	0.39	0.042	0.014	1.1	5.2
0.124	112	12.8	0.40	0.042	0.011	1.1	6.1

Table 93. Means and treatment comparisons for various elements extracted by DA reagent from three soils with residual 1AA and CSP treatments, sampled after *Zea mays* harvest.

Factor	Ca	Mg	K	Cu	Zn
	—Sum of squares for comparisons—				
Treatment comparison	**	**	**	**	
1 1AA,L					
2 1AA,Q	**	**	**		
3 CSP form		**			
4 CSP,L			**		
5 CSP,Q	*		*		
6 Form x rate,L					
7 Form x rate,Q				**	
8 CSP·1AA,L			**		*
9 CSP·1AA,Q					
10 1AA vs CSP	*	**	**		
11 CSP·1AA vs CSP+1AA		**	**	**	*
12 Control vs others		**	**		
Soils	**	**	**	**	**
Soils x treatments (as above)	**	**	**		*
1		**			
2	*	**	**		
3		**			
4			**		
5		*			
6		*			
7		*			
8			**		
9	*	**			
10	*	**	**		
11		**	**		
12		**	**		
Depths	**	**		**	
Depths x treatments (as above)	**	**	**		
1		*			
2	**	**	**		
3	**			*	
4					
5		**			
6		**			
7					
8			*		
9		**			
10	*	**	**		
11				**	
12		**			
Soils x depths	**	**	**	**	**

* and ** denote significance at the 0.05 and 0.01 level, respectively, and the letters L and Q stand for linear and quadratic, respectively.

Table 94. Mean height of maize grown on 0- to 15-cm depth of Athi soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Height		
		Weeks since emergence		
1AA	P	2	4	6
— kg/ha —		cm		
		Check		
0	0	40.0	66.1	82.6
		1AA		
0.031	0	35.1	60.1	75.7
0.062	0	35.1	61.2	74.9
0.124	0	37.4	61.6	76.9
		Powdered CSP		
0	28	45.9	81.8	105.3
0	56	43.3	84.2	108.6
0	112	45.4	87.8	113.3
		Pelletized CSP		
0	28	45.8	87.8	110.6
0	56	38.1	85.0	108.4
0	112	44.9	93.1	119.8
		Pelletized CSP with 1AA		
0.031	28	48.0	87.9	113.4
0.062	56	41.4	83.3	108.0
0.124	112	40.6	85.2	108.2

Table 95. Mean height of maize grown on 0- to 15-cm depth of Kabete soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Height		
		Weeks since emergence		
1AA	P	2	4	6
— kg/ha —		— cm —		
		Check		
0	0	37.4	85.2	117.3
		1AA		
0.031	0	44.7	93.0	127.6
0.062	0	44.9	89.3	120.6
0.124	0	45.1	88.3	117.9
		Powdered CSP		
0	28	45.9	100.3	130.8
0	56	47.7	99.8	132.8
0	112	54.8	112.3	140.2
		Pelletized CSP		
0	28	46.0	100.0	132.6
0	56	41.8	100.9	130.8
0	112	53.2	102.0	128.5
		Pelletized CSP with 1AA		
0.031	28	50.9	97.9	129.7
0.062	56	50.8	107.0	137.3
0.124	112	47.2	105.2	134.4

Table 96. Mean dry matter yield of maize tops and roots from maize grown on 0- to 15-cm depth of Athi and Kabete soils treated with indole acetic acid and three concentrated superphosphate sources at three rates.

		Dry matter yield of maize			
		Tops		Roots	
Rate		Athi (cm)	Kabete (cm)	Athi (cm)	Kabete (cm)
1AA	P	0-15	0-15	0-15	0-15
— kg/ha —		g			
		Check			
0	0	5.94	18.43	2.34	3.15
		1AA			
0.031	0	4.18	25.41	2.01	4.59
0.062	0	4.65	25.11	2.14	4.88
0.124	0	4.18	21.45	2.31	4.33
		Powdered CSP			
0	28	17.75	33.58	5.64	6.44
0	56	19.97	35.26	5.64	6.04
0	112	20.03	44.74	4.97	6.91
		Pelletized CSP			
0	28	20.13	30.34	5.34	5.15
0	56	22.84	38.56	5.32	6.87
0	112	23.79	42.43	5.30	6.43
		Pelletized CSP with 1AA			
0.031	28	22.59	30.98	6.32	5.23
0.062	56	23.20	38.57	6.54	6.00
0.124	112	23.29	40.42	6.19	6.66

Table 97. Mean analysis of maize tops sampled from 0- to 15-cm depth of Athi soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Maize top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		%				ppm			
		Check							
0	0	0.068	0.88	0.23	3.47	8	80	79	9
		1AA							
0.031	0	0.074	0.91	0.24	4.17	9	77	176	16
0.062	0	0.070	0.91	0.25	3.97	9	80	163	14
0.124	0	0.074	0.93	0.22	4.17	8	70	160	16
		Powdered CSP							
0	28	0.102	0.52	0.19	1.16	5	70	76	8
0	56	0.148	0.47	0.20	1.01	4	77	79	8
0	112	0.254	0.48	0.22	1.00	5	133	94	11
		Pelletized CSP							
0	28	0.121	0.50	0.21	1.12	5	90	84	8
0	56	0.156	0.42	0.18	0.94	5	120	96	9
0	112	0.236	0.42	0.18	0.78	4	70	88	9
		Pelletized CSP with 1AA							
0.031	28	0.104	0.42	0.16	0.94	7	107	64	8
0.062	56	0.155	0.44	0.19	0.85	4	90	77	8
0.124	112	0.234	0.41	0.17	0.81	3	83	75	9

Table 98. Mean analysis of maize tops sampled from 0- to 15-cm depth of Kabete soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Maize top composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
				Check					
0	0	0.105	0.76	0.28	2.73	7	110	133	88
				1AA					
0.031	0	0.088	0.62	0.26	2.00	6	77	101	59
0.062	0	0.097	0.60	0.27	2.13	6	67	89	59
0.124	0	0.101	0.69	0.28	2.16	7	97	97	75
				Powdered CSP					
0	28	0.104	0.51	0.27	1.57	6	47	112	42
0	56	0.121	0.46	0.28	1.10	7	67	157	51
0	112	0.141	0.36	0.25	0.88	5	47	137	42
				Pelletized CSP					
0	28	0.101	0.50	0.26	1.41	6	113	177	54
0	56	0.128	0.43	0.25	0.86	5	60	120	43
0	112	0.163	0.37	0.25	1.01	5	117	130	45
				Pelletized CSP with 1AA					
0.031	28	0.101	0.47	0.25	1.41	5	90	197	54
0.062	56	0.116	0.43	0.29	1.12	6	67	177	51
0.124	112	0.164	0.39	0.28	1.01	6	53	114	38

Table 99. Significant factors of the analysis of variances for maize tops responses to two soils treated with 1AA and CSP.

Factor	D.F.	Ca	Mg	K	Cu	Fe	Mn	Zn
		Response						
		Sum of squares						
Comparisons (C)	12	**	**	**	**			**
1	1							*
2	1							
3	1							
4	1	**		**				
5	1			*				
6	1							
7	1							
8	1				*			
9	1		**					
10	1		**	**	**			**
11	1	**	*	**	**			
12	1	**	*					**
Soils (S)	1	**	**	**			**	**
SXC	12	**	*	**	**		**	**
1	1							
2	1							
3	1							
4	1							
5	1							
6	1							
7	1							
8	1				**			*
9	1				**			
10	1	**	*	**			**	**
11	1	**	**	**			**	
12	1							**

* and ** denote significance at the 0.05 and 0.01 level, respectively, where the error term has 52 degrees of freedom (D.F.).

Table 100. Mean analysis of maize leaves sampled from maize grown on the 0- to 15-cm depth of Athi soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Maize leaf composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
				Check					
0	0	0.067	0.78	0.17	0.58	27	267	50	33
				1AA					
0.031	0	0.065	0.85	0.18	0.93	40	200	83	37
0.062	0	0.061	0.86	0.20	1.08	47	200	90	37
0.124	0	0.071	0.80	0.20	1.06	43	267	87	40
				Powdered CSP					
0	28	0.073	0.73	0.24	0.90	30	500	93	30
0	56	0.105	0.61	0.17	0.93	27	133	80	30
0	112	0.172	0.66	0.21	0.86	40	500	153	33
				Pelletized CSP					
0	28	0.081	0.67	0.20	0.83	30	167	80	33
0	56	0.112	0.61	0.15	0.93	20	200	83	37
0	112	0.128	0.51	0.13	0.71	30	167	103	50
				Pelletized CSP with 1AA					
0.031	28	0.078	0.72	0.17	0.83	33	333	77	30
0.062	56	0.118	0.54	0.14	0.82	23	167	77	33
0.124	112	0.114	0.58	0.12	0.61	30	200	80	43

Table 101. Mean analysis of maize leaves sampled from maize grown on the 0- to 15-cm depth of Kabete soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Maize leaf composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		%				ppm			
		Check							
0	0	0.077	0.82	0.25	1.22	33	233	137	100
		1AA							
0.031	0	0.056	0.86	0.29	1.13	33	233	137	90
0.062	0	0.068	0.85	0.28	1.08	27	200	110	77
0.124	0	0.085	0.90	0.34	1.23	30	233	103	80
		Powdered CSP							
0	28	0.062	0.75	0.27	0.96	27	300	113	80
0	56	0.086	0.71	0.29	1.02	30	200	170	70
0	112	0.116	0.80	0.35	0.82	27	133	137	57
		Pelletized CSP							
0	28	0.082	0.76	0.30	0.90	23	167	197	83
0	56	0.110	0.64	0.27	0.94	27	367	130	57
0	112	0.168	0.66	0.29	0.83	23	167	117	63
		Pelletized CSP with 1AA							
0.031	28	0.070	0.88	0.27	1.07	33	433	210	70
0.062	56	0.088	0.77	0.33	0.88	30	167	170	80
0.124	112	0.118	0.73	0.31	0.82	27	200	120	63

Table 102 Significant factors of the analysis of variance of maize leaf responses to two soils treated with IAA and CSP.

Factor	D.F.	Ca	Mg	K	Cu	Fe	Mn	Zn
		Response						
		Sum of squares						
Comparisons (C)	12	*			*	*		
1	1							
2	1							
3	1		*			*		
4	1							
5	1							
6	1		*				*	
7	1					**		
8	1	*						
9	1					*		
10	1	**		*	**			
11	1							*
12	1							
Soils (S)	1	**	**		*		**	**
SXC	12				*		*	
1	1							
2	1							
3	1					*		
4	1		*				*	*
5	1				*	*		
6	1							
7	1						*	
8	1						*	
9	1							
10	1		*		*			
11	1	*		*	*		*	
12	1							*

* and ** denote significance at the 0.05 and 0.01 probability level, respectively, where the error term has 52 degrees of freedom (D.F.).

Table 103. Mean analysis of maize roots sampled from maize grown on the 0- to 15-cm depth of Athi soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Maize root composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
				Check					
0	0	0.030	0.36	0.12	0.21	8	2667	297	31
				1AA					
0.031	0	0.026	0.35	0.13	0.13	9	3100	623	21
0.062	0	0.025	0.39	0.13	0.13	9	3533	567	26
0.124	0	0.027	0.49	0.16	0.13	13	4967	877	29
				Powdered CSP					
0	28	0.049	0.31	0.12	0.29	12	3867	653	24
0	56	0.062	0.32	0.12	0.24	12	4267	857	27
0	112	0.087	0.26	0.10	0.25	10	2033	540	18
				Pelletized CSP					
0	28	0.044	0.25	0.12	0.23	9	2567	537	17
0	56	0.061	0.24	0.11	0.23	8	2233	453	17
0	112	0.102	0.26	0.12	0.23	8	2267	410	19
				Pelletized CSP with 1AA					
0.031	28	0.044	0.27	0.13	0.25	14	2700	510	21
0.062	56	0.063	0.25	0.10	0.22	15	3300	510	25
0.124	112	0.116	0.24	0.11	0.28	12	3000	277	23

Table 104. Mean analysis of maize roots sampled from maize grown on the 0- to 15-cm depth of Kabete soil treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		Maize root composition							
1AA	P	P	Ca	Mg	K	Cu	Fe	Mn	Zn
— kg/ha —		— % —				— ppm —			
				Check					
0	0	0.052	0.39	0.13	0.49	12	1030	357	86
				1AA					
0.031	0	0.054	0.39	0.21	0.68	12	940	530	81
0.062	0	0.055	0.43	0.21	0.54	13	1367	517	85
0.124	0	0.059	0.38	0.19	0.62	10	1193	373	97
				Powdered CSP					
0	28	0.064	0.41	0.20	0.52	10	920	463	67
0	56	0.074	0.38	0.21	0.56	10	683	643	64
0	112	0.090	0.31	0.13	0.50	8	757	510	52
				Pelletized CSP					
0	28	0.071	0.40	0.16	0.63	10	740	700	63
0	56	0.080	0.36	0.17	0.42	9	780	427	54
0	112	0.095	0.32	0.16	0.49	8	607	397	48
				Pelletized CSP with 1AA					
0.031	28	0.070	0.48	0.16	0.45	9	727	683	51
0.062	56	0.075	0.41	0.19	0.49	10	1013	710	60
0.124	112	0.106	0.38	0.19	0.60	9	743	537	58

Table 105 Significant factors of the analysis of variance of maize root responses to two soils treated with IAA and CSP.

Factor	D.F.	Ca	Mg	K	Cu	Fe	Mn	Zn
		Response						
		Sum of squares						
Comparisons(C)	12	**	**		*	**	*	
1	1					**		
2	1							
3	1				*	**	*	
4	1	*	*			**		
5	1					*		
6	1		*			**		
7	1					*	*	
8	1	*						
9	1					*		
10	1	**	**		*	**		**
11	1				*	*		
12	1		*				**	**
Soils(S)	1	**	**			**		**
SXC	12	**			**	**		
1	1	**			**	**	*	
2	1					*		
3	1					**		
4	1					**		
5	1					**		
6	1					**		
7	1					**		
8	1							
9	1							
10	1	**	**			**		**
11	1	**			**		**	
12	1		*		**	**		**

* and ** denote significance at the 0.05 and 0.01 level, respectively, where the error term has 52 degrees of freedom (D.F.).

Table 106. Mean analysis of 0- to 15-cm depth of Athi soil sampled after maize growth treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		P extracted	Extractable cations by DA method				
1AA	P	DA	Ca	Mg	K	Cu	Zn
— kg/ha —		ppm	———	% ———		— ppm —	
			Check				
0	0	4.8	0.54	0.060	0.017	0.8	2.7
			1AA				
0.031	0	4.7	0.56	0.061	0.017	0.9	2.2
0.062	0	4.3	0.55	0.061	0.017	0.9	2.3
0.124	0	5.9	0.54	0.062	0.018	0.9	2.1
			Powdered CSP				
0	28	8.3	0.52	0.058	0.012	0.8	1.8
0	56	37.8	0.53	0.060	0.011	0.7	1.9
0	112	49.8	0.54	0.060	0.012	0.7	2.1
			Pelletized CSP				
0	28	7.6	0.54	0.060	0.011	0.7	2.1
0	56	36.4	0.53	0.061	0.012	0.7	2.0
0	112	80.8	0.55	0.060	0.011	0.7	2.0
			Pelletized CSP with 1AA				
0.031	28	18.9	0.53	0.059	0.012	0.7	2.4
0.062	56	30.3	0.54	0.058	0.012	0.8	2.0
0.124	112	46.5	0.52	0.057	0.011	0.6	2.2

Table 107. Mean analysis of 0- to 15-cm depth of Kabete soil after maize growth treated with indole acetic acid and three concentrated superphosphate sources at three rates.

Rate		P extracted	Extractable cations by DA method				
1AA	P	DA	Ca	Mg	K	Cu	Zn
— kg/ha —		ppm	— % —			— ppm —	
			Check				
0	0	8.9	0.68	0.067	0.020	0.8	52
			1AA				
0.031	0	7.9	0.72	0.073	0.020	0.8	52
0.062	0	8.7	0.72	0.071	0.014	0.7	50
0.124	0	7.7	0.68	0.066	0.014	0.8	51
			Powdered CSP				
0	28	13.3	0.68	0.006	0.011	0.9	52
0	56	20.7	0.68	0.067	0.012	0.8	52
0	112	47.3	0.70	0.066	0.011	0.8	51
			Pelletized CSP				
0	28	14.3	0.69	0.068	0.018	0.8	52
0	56	24.0	0.69	0.065	0.010	0.7	48
0	112	85.1	0.70	0.064	0.010	0.7	50
			Pelletized CSP with 1AA				
0.031	28	15.5	0.69	0.067	0.020	0.8	50
0.062	56	22.8	0.70	0.068	0.012	0.8	50
0.124	112	52.2	0.68	0.062	0.011	0.7	46

Table 108. Significant factors of the analysis of variance for eucalypt tops in response to three soils treated with 1AA and CSP.

Factor	D.F.	Ca	Mg	K	Cu	Fe	Mn	Zn
						Response		
						Sum of squares		
Comparison								
(C)	12	**	**	**	**	*		**
1	1							
2	1							
3	1					**		
4	1							
5	1							
6	1	*						**
7	1	*						
8	1	*	*					*
9	1							
10	1	**	**	**	**		*	**
11	1	*	**	**	**			*
12	1		*		**		*	
Soils(S)	2	**	**	**	**	**	**	**
SXC	12	**	**	**	**		**	**
1								*
2								
3						*		
4						*		
5		**						
6								
7								
8								
9								
10		**	**		**	*	**	**
11			**	**	**	*		
12			**	**				

* and ** denote significance at the 0·05 and 0·01 level, respectively, where error term has 156 degrees of freedom (D.F.).

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BIOGRAPHICAL SKETCH

Joseph Kipkorir A. Keter, son of James and Grace Bira, was born on November 21, 1944, at Kericho, Kenya. He attended his high schools at Kericho Secondary and Friends School Kamusinga. He graduated from the University of Nairobi in 1971 with a B.Sc. in chemistry and geology. In 1972 he obtained a German scholarship to study for an M.Sc. degree in soil science in the University of Nairobi. He obtained the M.Sc. degree in soil science in February 1975 following which he was appointed a lecturer in soil science in the University of Nairobi. He taught there until August, 1977, when he was awarded an USAID scholarship to study for a Ph.D. degree in soil science (soil chemistry) at the University of Florida.

He is a member of the American and International Societies of Soil Science.

Joseph Keter is married to Mary Chepkemoi Keter and they have one child, Winnie Chepkirui, aged 3.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

John G. A. Fiskell

John G. A. Fiskell, chairman
Professor of Soil Science

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Victor W. Carlisle

Victor W. Carlisle
Professor of Soil Science

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L.B. Comerford (for W.L. Pritchett)

William L. Pritchett
Professor of Soil Science

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Hugh Popenoe

Hugh L. Popenoe
Professor of Soil Science

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P. V. Rao

Pejaver V. Rao
Professor of Statistics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Bob G. Volk for D.F. Rothwell

Donald F. Rothwell
Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality. as a dissertation for the degree of Doctor of Philosophy.

August, 1981

Jack L. Fry
Dean, College of Agriculture

Dean, Graduate School